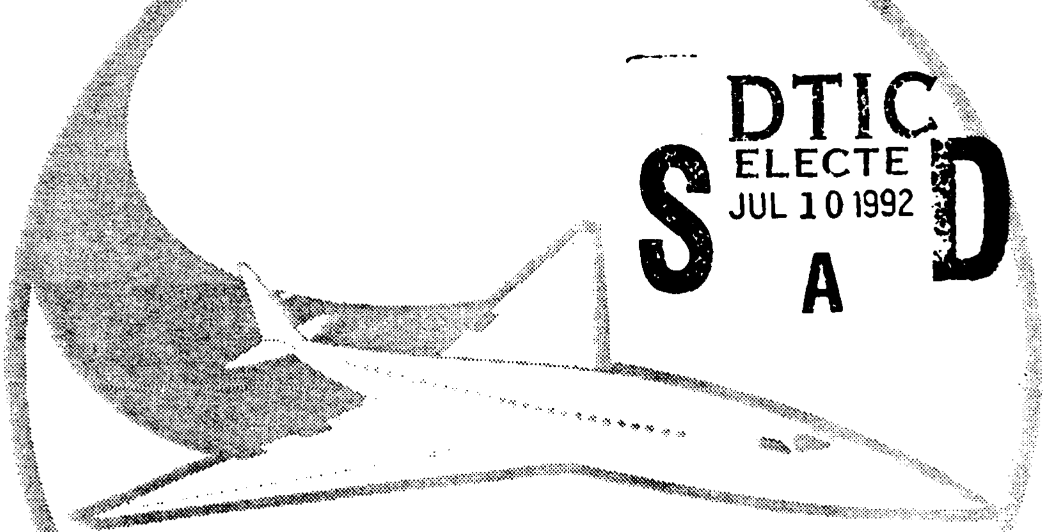
(2)

DOT/FAA/CT-91/10

FAA Technical Center
Atlantic City International Airport
N.J. 08405

Turbine Aircraft Engine Operational Trending and JT8D Static Component Reliability Study



March 1992

Final Report

This document is available to the U.S. public through the National Technical Information Service, Springfield, Virginia 22161

U.S. Department of Transportation
Federal Aviation Administration

Department of the Air Force
Oklahoma City Air
Logistics Center

NOTICE

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
DOT/FAA/CT-91/10		

4. Title and Subtitle TURBINE AIRCRAFT ENGINE OPERATIONAL TRENDING AND JT8D STATIC COMPONENT RELIABILITY STUDY	5. Report Date March 1992 6. Performing Organization Code
7. Author(s) A.Bruce Richter, Margaret Ridenour-Bender, Mike Tsao	8. Performing Organization Report No. DOT/FAA/CT-91/10
9. Performing Organization Name and Address Science Applications International Corp. Logistics Technology Division 4335 Piedras Drive, West Suite #223 San Antonio, Texas 78228	10. Work Unit No. (TRAIS) 11. Contract or Grant No. F04606-89-D-036
12. Sponsoring Agency Name and Address U.S. Department of Transportation and * Federal Aviation Administration Technical Center Atlantic City International Airport, NJ 08405	13. Type of Report and Period Covered Final Report 3/28/90 To 3/28/91 14. Sponsoring Agency Code

15. Supplementary Notes

*Department of the Air Force, Oklahoma City Air Logistics Center
Technical Center Project Manager: David Galella

16. Abstract

The engine subpanel of the June 1988 International Conference on Aging Airplanes identified the need to study aircraft turbine engine static components for reliability problems resulting from aging effects. This study trended in-flight shutdowns and unscheduled removal rates of JT8D, CF6, and JT3D turbine aircraft engines for the two year period of February 1988 through January 1990. Specific engine components on the JT8D engines of air carriers frequently exceeding the industry norm during the trending period were identified. This review resulted in the following types of component failures occurring: hard failures, wear and tear/inspection failures, structural failures, diagnostic troubleshooting, and maintenance errors. In addition to specific JT8D engine components being identified, an ultrasonic inspection procedure was developed for the JT8D engine outer combustor case boss.

17. Key Words	18. Distribution Statement
Actuarial Analysis Case Drain Boss Weld In-flight Shutdowns Service Difficulty Report (SDR) Data Base Ultrasonic Inspection Unscheduled Engine Removals	Document is available to the public through the National Technical Information Service, Springfield Virginia 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	76	

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

PREFACE

This report was prepared by Science Applications International Corporation under contract number F04606-89-D-036 Delivery Order Number SD06 with the Department of the Air Force, Oklahoma City Air Logistics Center, and the Federal Aviation Administration (FAA) Technical Center.

The JT8D, CF6, and JT3D engine trending analysis was conducted by the Logistics Technology Division located in San Antonio, Texas. A. Bruce Richter and Margaret Ridenour-Bender performed the actuarial data analysis. The development of the Nondestructive Inspection (NDI) technique for the JT8D engine outer combuster cases was accomplished by the Ultra Image International Division located in New London, Connecticut, under the direction of Robert H. Grills and Mike C. Tsao.

TABLE OF CONTENTS

	Page
EXECUTIVE SUMMARY	vii
INTRODUCTION	1
Purpose	1
Background	1
PROCEDURE	1
Actuarial Data Sources	1
Trending Methodology	2
Component Performance Analysis	6
DISCUSSION AND RESULTS	6
Actuarial Trending Results	6
Component Failure Results	25
Engine Case Failure Analysis	28
Ultrasonic Scanner Design	29
Scanner Demonstration Results	30
CONCLUSIONS	41
APPENDICES	
A - Component Performance by Disguised Airline	
B - Ultra Image III Specifications	
C - NDI Procedure Description	

LIST OF FIGURES

Figure		Page
1	Sample Data Comparing Airline ABC To The Rest Of The Industry For B-727 JT8D Unscheduled Engine Removal Rates	19
2	Sample Data Comparing Airline ABC To The Rest Of The Industry For B-727 JT8D In-flight Engine Shutdown Rates	20
3	PWA Outer Combustor Case Inspection Design	29
4	Schematic Of JT8D Engine And Locations Of The Drain Boss Welds	31
5	Schematic Of Prototype JT8D Motorized Boss Weld Scanner	32
6	Prototype Motorized JT8D Boss Weld Scanner	33
7	JT8D Boss Weld Specimen And Calibration Standard	34
8	Prototype Motorized JT8D Boss Weld Scanner On Calibration Standard	35
9	Ultra Image III™ With Prototype Scanner Testing On Calibration Standard	36
10	Ultra Image III™ Inspection Of Calibration Standard	37
11	Ultrasonic Scanner Results Of Four Simulated Flaws In A PWA Drain Boss Sample	38
12	Ultrasonic Scanner Results On A PWA Drain Boss With No Flaws	39
13	Calibration Test Standard Using New Software	40

LIST OF TABLES

Table		Page
1	B-727 / JT8D Engine In-flight Shutdowns	4
2	B-727 / JT8D Engine Removals	5
3	In-flight Shutdown Calculations	7
4	Engine Removal Calculations	13
5	B-727 / JT8D Airline Macro Scan	21
6	B-737 / JT8D Airline Macro Scan	21
7	DC-9 / JT8D Airline Macro Scan	22
8	A-300 / CF6 Airline Macro Scan	22
9	B-767 / CF6 Airline Macro Scan	23
10	DC-10 / CF6 Airline Macro Scan	23
11	B-707 / JT3D Airline Macro Scan	24
12	DC-8 / JT3D Airline Macro Scan	24
13	Masked Airlines Operating JT8D Engines With Various Airframes Identified For Component Performance Analysis	25
14	JT8D Component Failure Trends 1983 To 1990	26

EXECUTIVE SUMMARY

The engine subpanel of the June 1988 International Conference on Aging Airplanes identified the need to study aircraft turbine engine static components for reliability problems due to aging effects and, where needed, to develop improved inspection techniques for these static components. Subsequently, the Federal Aviation Administration (FAA) Technical Center and the U.S. Department of the Air Force jointly contracted Science Applications International Corporation (SAIC) to carry out such an investigation.

The approach taken by SAIC was to trend the in-flight shutdowns and unscheduled removal rates of JT8D, CF6, and JT3D turbine aircraft engines for the two year period from February 1988 to January 1990. These data are currently collected each month by the FAA and published in the Air Carrier Aircraft Utilization and Propulsion Reliability Reports. Using actuarial data from these reports, monthly industry-wide averages of shutdown and unscheduled removal rates were calculated for each airframe and engine combination. Rate data from individual U.S. operators of those engines were then compared to the monthly industry averages and the results were trended to determine which operators were experiencing higher than normal engine shutdown and removal rates. Since the ultimate purpose of this study was to identify possible reliability problems with engine static components, no airlines or operators were identified. For this reason, all operator names throught this report have been masked to ensure anonymity.

Once the operators that frequently exceeded the industry normal rates for shutdowns and removals were determined, the FAA's Service Difficulty Report (SDR) data base was queried for each of those operators to determine which components may have caused the higher than normal shutdowns and removals. Although trending was accomplished for the JT8D, CF6, and the JT3D, the scope of this report was to perform the SDR component analysis for only the JT8D engine. The JT8D was chosen as the focus of this study because it has been in service for over twenty years, its application is on three separate airframes (B-727, B-737, and DC-9), and because there are currently over 10,000 such engines still in commercial service.

From the actuarial trending, ten operators of JT8D engines were selected to be further analyzed using data from the SDR system. For these 10 operators, the SDR data base was analyzed for the period from January 1983 to May 1990 to identify components possibly responsible for the higher than normal shutdowns and removals. The following components and conditions were discovered:

Hard Failures

- #3 Bearing
- #4.5 to #6 Oil Bearing Tube

Wear and Tear / Inspection Failures

- 13th Stage Bleed Air Duct
- Turbine Blades

Structural Failures

- Case Cracking

Diagnostic Troubleshooting

- Fuel Controls, Pumps

Maintenance Practices

- Oil Cap Unsecured
- Fuel / Oil Heater Valve Wired Open
- Oil Screen Studs Pulled Loose
- Oil Seals Pinched

Based upon discussions with Pratt and Whitney Aircraft (PWA) and the FAA, SAIC developed an improved technique to inspect the three outer combustor case drain boss welds for cracking. Although PWA had developed an on-wing ultrasonic inspection technique that could inspect the weld near the bolt holes of the bosses for cracking, it was possible to miss cracks developing near the weld but away from the bolt holes. To improve this inspection, an automated ultrasonic scanner system was designed by SAIC that could access the drain bosses through the exhaust duct of the engine and scan a larger area of the drain boss welds and bolt holes. The scanner was tested on several combustor cases at PWA and successfully detected the notches specified in the PWA Alert Service Bulletin 5676, revision 6, Appendix B. The scanner was designed so that with minor modification, it could be applicable to other commercial engines.

This study concluded that the FAA Air Carrier Aircraft Utilization Propulsion Reliability Report contains valuable actuarial information that can be used to document reliability trends of specific engines. The actuarial trending and component failure analysis using the SDR system were useful in determining which components may require modification and/or nondestructive inspection procedures to ensure their integrity. Based upon data collected from the trending and SDR analysis, the outer combustor case on the JT8D engine was chosen and demonstrated to be one static part that could be inspected more thoroughly by applying state of the art ultrasonics and automated scanning techniques.

INTRODUCTION

PURPOSE

The purpose of this study was to conduct an actuarial trending analysis to review the operational reliability of the JT8D engine, and also to develop a successful nondestructive inspection (NDI) procedure for the JT8D engine outer combustor cases. Observations, conclusions, and recommendations on specific airline operational performance and maintenance practices were not part of the purpose of this task. In that regard, no identities of specific airlines performance and component failures have been made. Actuarial data were also collected on the CF6 and JT3D engines. Preliminary reliability results were calculated on the CF6 and JT3D, however, a more in-depth component failure analysis was not performed for this phase of the work. The objectives of the NDI program were to design and construct a prototype automatic scanner and to develop an inspection procedure for on-aircraft inspection of JT8D combustor case drain boss welds using an ultrasonic imaging method. The NDI procedure was developed so that with minor modifications, the procedure could be applicable to other engines such as the CF6, JT3D, and JT9D.

BACKGROUND

The aerospace industry's attention toward aging aircraft has generally been focused upon aircraft fuselage structures. The thought about aircraft engines has historically been that engines were periodically "regenerated" through scheduled maintenance and modification programs. For many of the dynamic components, like blades, disks, and spacers, this is basically true and applies equally to some static parts like vanes and combustors. However, other static parts such as fan, compressor, combustor, diffuser, turbine, and exhaust cases are not life limited and therefore not subject to periodic replacement.

The engine subpanel of the June 1988 International Conference on Aging Airplanes identified the need for improved nondestructive inspection (NDI) procedures for aircraft turbine engine cases and frames. The composite maintenance concept for airline engines emphasizes maximum use of on-aircraft maintenance and phased maintenance of rotors and static parts based upon life limits. However, since engine cases and frames provide the skeleton to which other components are attached, these cases and frames are rarely removed and inspected. Some cases now have in excess of 30,000 hours of operating time. Without specific life limits assigned to cases, there is no requirement for scheduled shop removals and an in-depth inspection cycle.

The JT8D was chosen for this study because of its proven operational service. The JT8D is used on three separate airframes: the B-727, B-737, and DC-9. Over 10,000 of these engines are in service and many have been in operation for over 20 years. This engine has delivered excellent service, although several air carriers have reported higher than normal in-flight shutdowns and engine removal rates.

PROCEDURE

ACTUARIAL DATA SOURCES

This study included an actuarial scan of the JT8D, CF6, and JT3D engine inventories to determine which air carriers reported higher than normal engine in-flight shutdowns and engine removal rates. The data analysis went one step further for the JT8D engine since the objective was to identify those JT8D engine components recorded as causing the high rates of in-flight shutdowns and engine removals. The following sources of information were used for this actuarial study:

1. The FAA Air Carrier Aircraft Utilization & Propulsion Reliability Report, as published on a monthly basis by the Aviation Standards National Field Office at Oklahoma City, OK. This report provides the following monthly information, by aircraft engine type, and air carrier:

- Number of aircraft by aircraft model and engine series
- Engine shutdowns & shutdowns/1000 hours
- Engine removals & removals/1000 hours for premature unscheduled removals
- 3-month history of engine shutdowns per 1000 hours

2. FAA Service Difficulty Reports (SDRs) as published by the Aviation Standards National Field Office with each issue covering a one week period. The engine section of this report provides:

- Information on a specific engine incident, identifying the air carrier involved, aircraft model, aircraft serial number, description of the problem, and often the investigation results and corrective action taken.

3. Printouts from the FAA Operational Systems Branch, AVN-120 on JT8D-1, -7, -15, -17, engine component failures from January 1983 through May 1990 that provide:

- Information on specific engine incidents, identifying the air carrier involved, aircraft and engine dash model, date of component failure, take-off aborts, engine shutdowns, flights diverted, description of failure, teardown results, and corrective actions taken.

TRENDING METHODOLOGY

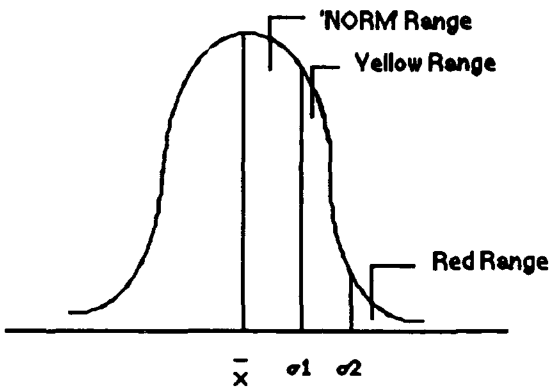
The actuarial data initially analyzed in this study came from the monthly FAA Air Carrier Aircraft Utilization and Propulsion Reliability Reports. For the 24-month period from February 1988 through January 1990, all US operated JT8D, JT3D, and CF6 engine in-flight shutdowns and unscheduled engine removal rates, by month and airline, were trended. From these data, monthly, industry-wide average rates of in-flight shutdowns and engine removals were calculated for each of the following airframe/engine combinations: B-727/JT8D, B-737/JT8D, DC-9/JT8D, A-300/CF6, B-767/CF6, DC-10/CF6, B-707/JT3D and DC-8/JT3D.

Along with the average or normal rates, first and second standard deviations were also calculated per month, for each airframe/engine combination. For each month, an operator's reported rates of in-flight shutdowns and engine removals were compared with the norm for a particular airframe/engine combination. When the operator's rate was between one and two standard deviations of the norm, the condition was coded "Y" for yellow. A yellow condition was considered by SAIC to be a possible indicator of a reliability problem at that airline. When an operator's rate was greater than two standard deviations from the norm, the condition for that month was coded "R" for red. Red conditions were considered by SAIC to be a definite indicator of a reliability problem. The following equations were used in this standard deviation analysis:

- number of datum entries (e.g. number of airlines); N
- summation of datum entries (e.g. monthly shutdown removal rates) ΣX
- average of data entries; $\Sigma X/N$
- standard deviation; SD:

$$SD = \left(\frac{N\Sigma X^2 - (\Sigma X)^2}{N(N-1)} \right)^{1/2}$$

The yellow range was calculated as:
(Average X+1SD) > (Average X+2SD)
The red range was calculated as:
> (Average X+2SD)



Tables 1 and 2 are samples of the yellow and red trending performed for each US airline operating either the JT8D, CF6 or JT3D engines. Again, this type of trending was performed separately for both in-flight shutdown data and engine removal data. It should be noted that months containing a "-" correspond to a condition when the rate was equal to or below the normal rate value for that airframe/engine combination. Also, some months may contain two "Y"s or two "R"s which corresponds to an airline that exceeded the normal range while operating two different aircraft model series, (for example the 727-100 and 727-200 aircraft model operating with a JT8D-7B engine). When either the aircraft model series number or the engine model series number was not specified, the FAA Air Carrier Aircraft Utilization & Propulsion Reliability Report identifies this lack of information by placing an asterisk (*) adjacent to the aircraft model or the engine model. This same identification was used in the actuarial trending throughout this report.

A reasonableness test was applied to the calculated standard deviation with consideration given to fleet size, daily utilization hours, and engine shutdown and removal rates. Fleet size among the air carriers varied by aircraft type, but the utilization rate was comparable among the carriers. The use of rates for engine shutdowns and removals minimized any skewing of the trending data from carriers with large and/or small inventories corresponding with large and/or small numbers of incidents.

In order to normalize these data and to calculate a more accurate and true standard deviation, two screening criteria were established. If an airline's number of aircraft was less than 8 (which correlates to 24 engines on the B-727, 16 engines on the B-737, 16 engines on the DC-9, 16 engines on the A-300, 16 engines on the B-767, 24 engines on the DC-10, 32 engines on the B-707, and 32 engines on the DC-8), and the rate (number of incidences per 1000 fleet operating hours) was greater than 0.75 for in-flight shutdowns and engine removals, these data were not included in the calculation. However, the entry was included for the overall trending analysis.

TABLE 1: B-727/JT8D ENGINE IN-FLIGHT SHUTDOWNS

Example of "Y" and "R" data collected from partial list of airlines operating B-727 with JT8D engines that experienced in-flight shutdowns from January 1989 through January 1990

AIRLINE	JAN '89	FEB '89	MAR '89	APR '89	MAY '89	JUN '89	JUL '89	AUG '89	SEPT '89	OCT '89	NOV '89	DEC '89	JAN '90
CTA (*)	-	-	-	-	Y	-	-	-	-	-	-	-	-
CTA (7)	-	-	-	-	-	-	R	Y	-	-	-	-	-
ABC (*)	-	Y	-	R	R	-	R	Y	R	-	R	Y	Y
BKB (7B)	-	-	-	-	-	-	-	Y	-	-	Y	-	-
BKB (17)	-	-	-	-	R	-	Y	-	-	R	-	-	Y
BKB (15)	-	R	-	Y	Y	-	-	-	Y	-	Y	-	-
RAB(7B)	-	-	-	R	Y	Y	-	Y	Y	Y	-	-	-
RAB (15)	-	-	-	-	-	-	-	-	-	-	-	-	-
FPC (15)	-	-	-	Y	Y	-	-	-	-	-	R	-	-
XYZ (7)	-	-	-	-	-	-	-	-	-	-	-	-	-
XYZ (17R)	-	-	-	-	-	-	-	-	-	R	-	R	-
XYZ (15)	-	-	-	-	-	-	R	-	Y	Y	-	Y	-
LWZ (9A)	-	-	-	Y	-	-	-	-	Y	-	-	-	-
LWZ (*)	-	-	-	-	-	-	-	-	-	-	-	-	-
LWZ (7B)	-	-	-	-	-	-	-	-	-	-	-	R	-
DDA (7B)	-	-	-	-	Y	-	-	-	-	Y	-	-	-
DDA (7B)	-	-	-	R	-	-	-	-	Y	-	R	-	-
DDA (9A)	-	-	-	Y	R	-	-	-	-	Y	Y	-	YR
DEF (7)	-	-	-	-	-	R	-	Y	R	-	Y	-	-
DEF (17A)	-	-	Y	-	-	-	-	-	R	R	-	-	-
FFF (7)	-	-	-	-	-	-	-	-	-	-	-	-	-
FFF (7B)	Y	-	-	-	-	-	R	R	-	-	R	-	-
QQQ (7B)	-	-	Y	-	-	R	-	-	-	-	-	-	-
EEE (7B)	R	-	R	-	-	-	-	-	-	-	-	-	-
PPP (7)	-	-	-	-	-	-	R	-	-	-	-	-	-
UUU (7B)	-	-	-	-	-	-	-	-	-	-	-	-	-

TABLE 2: B-727/JT8D ENGINE REMOVALS

	Example of "Y" and "R" data collected from partial list of airlines operating B-727 with JT8D engines that experienced unscheduled engine removals from January 1989 thru January 1990												
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC	JAN
AIRLINE	'89	'89	'89	'89	'89	'89	'89	'89	'89	'89	'89	'89	'90
CTA (*)	-	-	Y	-	Y	-	-	-	-	-	-	Y	-
CTA (7)	-	-	-	-	-	-	R	R	-	-	-	-	-
DDA (15)	-	Y	Y	-	-	-	-	-	-	Y	-	-	-
DDA (9A)	-	-	-	-	Y	-	R	-	-	-	YR	-	-
DDA(7B)	Y	-	-	-	Y	YR	YR	-	Y	R	-	-	-
XYZ (17R)	-	-	-	-	-	-	-	-	-	-	-	R	-
XYZ (15)	-	-	-	-	-	R	-	R	Y	-	Y	Y	-
XYZ (7)	-	-	-	R	R	R	R	R	-	-	-	Y	-
BKB (7B)	-	-	Y	-	Y	-	-	-	-	-	R	R	-
BKB (15)	-	Y	Y	-	R	-	-	-	Y	-	Y	R	-
BKB (17)	Y	-	-	-	-	Y	-	-	R	-	Y	-	-
LWZ (7B)	-	-	Y	-	-	Y	-	-	R	-	-	-	Y
LWZ (9A)	Y	-	-	-	-	-	-	-	Y	-	-	-	-
MRM (9A)	-	-	-	-	-	Y	-	-	-	-	-	-	-
MRM(17R)	-	-	-	-	Y	-	-	-	-	-	-	-	-
MRM (15)	-	-	-	-	-	-	R	-	-	-	-	-	-
MRM (7B)	-	-	-	-	-	-	-	-	-	-	-	-	-
GGA (15)	-	-	-	-	-	-	Y	Y	Y	-	-	-	-
GGA (17)	-	-	-	Y	Y	-	Y	-	R	Y	Y	-	Y
FPC (15)	-	-	-	-	-	-	YY	-	-	-	-	-	-
RAB (7B)	-	-	-	-	-	-	R	Y	-	-	-	Y	-
JKL (15)	-	R	-	-	R	-	-	R	-	-	-	-	-
JKL (7B)	R	R	R	R	Y	-	-	R	-	Y	Y	Y	-
GHI(7B)	-	-	-	-	-	-	-	-	R	-	-	-	-
GHI (15)	R	-	-	-	-	-	R	-	-	-	-	-	-
GHI (17)	R	-	-	Y	-	-	R	-	RRR	R	-	R	-
GHI (9)	-	R	-	-	-	-	-	-	-	-	-	-	-
OTT (*)	-	-	-	-	-	-	-	-	-	-	-	-	-
OTT (15)	-	-	-	-	-	-	-	-	-	-	-	-	-
OTT (7B)	-	-	-	-	-	-	-	-	-	Y	-	-	-

If the entry was included in the calculation for an airline with a small engine population and an excessive rate, these data would be skewed to the right (high). Therefore, this screening criteria allowed for a more accurate trending analysis.

The final aspect of this actuarial trending was to determine which airlines consistently exceeded the industry norm of in-flight shutdowns and engine removal rates. The purpose of this macro analysis was to determine which airlines may be having engine reliability problems and to review those engine components causing the service difficulties. Note, that this macro analysis was performed only for the JT8D engine and not for the CF6 or JT3D.

COMPONENT PERFORMANCE ANALYSIS

Once the macro scan ranking was completed, a detailed analysis of JT8D component failures was conducted. A printout was requested on JT8D engine component failures as recorded in the SDRs. This printout covered the timeframe of 1983 through April 1990. Specific information provided included the following: operating condition that occurred, which engine incurred the damage, aircraft model and serial number, engine model and serial number, airline experiencing the incident, and date of the incident. A brief narrative was included in this information describing the incident and corrective action taken. This narrative would document whether a take-off was aborted, a flight turn-back occurred, if the flight was diverted, and whether or not an engine flameout occurred. Each of these flight occurrences was considered significant in determining the severity of the specific JT8D engine component failure.

The information from this printout was used to develop the JT8D engine component failure trend. The trend identifies the component failures and the number of failure occurrences. This in-depth component failure analysis was conducted on those air carriers identified as having consistently higher than normal in-flight shutdown and engine removal rates for the 24-month trending period.

DISCUSSION AND RESULTS

ACTUARIAL TRENDING RESULTS

Data for the 24 month period from February 1988 to January 1990 were collected for the following airframe/engine configurations: B-727/JT8D, B-737/JT8D, DC-9/JT8D, A-300/CF6, B-767/CF6, DC-10/CF6, B707/JT3D and DC-8/JT3D. For each airframe/engine combination, the industry average and standard deviation for in-flight shutdowns and unscheduled engine removal rates per 1000 hours of operating time were calculated. For this study the industry normal range is the monthly average plus one standard deviation. The yellow range is greater than one standard deviation but less than two standard deviations from the industry average. The red range is greater than two standard deviations form the industry average. Summary data of the in-flight shutdown calculations by month are listed in table 3 and data concerning engine removal calculations are listed in table 4.

With the monthly industry norms calculated, bar charts comparing individual airlines to the monthly norms for the respective airframe/engine combinations were developed. Figures 1 and 2 are examples of such charts. The percentage of months that each airline operated over the industry's normal rate of in-flight shutdown and engine removals was determined The airlines which most often exceeded the monthly normal rates were identified for each airframe/engine combination. A masked listing of these airlines is contained in tables 5 through 12. The airlines using JT8D engines that most frequently exceeded the norms were then analyzed by SAIC via the FAA's SDR system. Again, it should be noted that the ranking of airlines by percent of monthly exceedances was necessary to facilitate the identification of JT8D components causing the exceedances and not to target individual airlines in any way.

TABLE 3: IN-FLIGHT SHUTDOWN CALCULATIONS

	FEB '88	MAR '88	APR '88	MAY '88	JUN '88	JUL '88	AUG '88	SEPT '88
B-727/JT8D								
Average (X)	0.03	0.01	0.01	0.02	0.02	0.02	0.04	0.04
Standard Dev.	0.09	0.02	0.04	0.07	0.07	0.05	0.11	0.11
Industry Norm	X < .12	X < .03	X < .05	X < .09	X < .09	X < .07	X < .15	X < .15
Yellow Range	.12 < X < .21	.03 < X < .05	.05 < X < .09	.09 < X < .16	.09 < X < .16	.07 < X < .12	.15 < X < .26	.15 < X < .26
Red Range	X > .21	X > .05	X > .09	X > .16	X > .16	X > .12	X > .26	X > .26
B-737/JT8D								
Average (X)	0.01	0.02	0.01	0.01	0.02	0	0.02	0
Standard Dev.	0.03	0.06	0.02	0.02	0.02	0.01	0.05	0.02
Industry Norm	X < .04	X < .08	X < .03	X < .03	X < .04	X < .01	X < .07	X < .02
Yellow Range	.04 < X < .07	.08 < X < .14	.03 < X < .05	.03 < X < .05	.04 < X < .06	.01 < X < .02	.07 < X < .12	.02 < X < .04
Red Range	X > .07	X > .14	X > .05	X >.05	X > .06	X > .02	X > .12	X > .04
DC-9/JT8D								
Average (X)	0.01	0.01	0.01	0.01	0	0.01	0.01	0.01
Standard Dev.	0.05	0.03	0.03	0.04	0.01	0.02	0.04	0.04
Industry Norm	X < .06	X < .04	X < .04	X < .05	X < .01	X < .03	X < .05	X < .05
Yellow Range	.06 < X < .11	.04 < X < .07	.04 < X < .07	.05 < X < .09	.01 < X < .02	.03 < X < .05	.05 < X < .09	.05 < X < .09
Red Range	X > .11	X > .07	X > .07	X > .09	X > .02	X > .05	X > .09	X > .09
A-300/CF6								
Average (X)	0.09	0	0	0	0.02	0	0.07	0.05
Standard Dev.	0.1	0	0	0	0.04	0	0.09	0.1
Industry Norm	X < .19	0	0	0	X < .06	0	X < .16	X < .15
Yellow Range	.19 < X < .29	0	0	0	.06 < X < .10	0	.16 < X < .25	.15 < X < .25
Red Range	X > .29	0	0	0	X >.10	0	X > .25	X > .25

TABLE 3: IN-FLIGHT SHUTDOWN CALCULATIONS (CONTINUED)

	OCT '88	NOV '88	DEC '88	JAN '89	FEB '89	MAR '89	APR '89	MAY '89
B-727/JT8D								
Average (X)	0.06	0.04	0.04	0.07	0.02	0.04	0.01	0.01
Standard Dev.	0.17	0.12	0.11	0.18	0.06	0.15	0.02	0.03
Industry Norm	X < .23	X < .16	X < .15	X < .25	X < .08	X < .19	X < .03	X < .04
Yellow Range	.23 < X< .40	.16 < X < .28	.15 < X < .26	.25 < X < .43	.08 < X < .14	.19 < X < .34	.03 < X < .05	.04 < X < .07
Red Range	X > .40	X > .28	X > .26	X > .43	X > .14	X > .34	X > .05	X > .07
B-737/JT8D								
Average (X)	0.02	0.04	0.01	0.02	0.04	0.02	0.02	0.04
Standard Dev.	0.05	0.1	0.02	0.06	0.12	0.06	0.06	0.09
Industry Norm	X < .07	X < .14	X < .03	X < .08	X < .16	X < .08	X < .08	X < .13
Yellow Range	.07 < X < .12	.14 < X < .24	.03 < X < .05	.08 < X < .14	.16 < X < .28	.08 < X < .14	.13 < X < .24	.13 < X < .24
Red Range	X > .12	X > .24	X > .05	X > .14	X > .28	X > .14	X > .14	X > .24
DC-9/JT8D								
Average (X)	0.01	0.03	0	0.01	0.01	0.02	0.02	0.01
Standard Dev.	0.04	0.06	0.02	0.02	0.04	0.06	0.1	0.02
Industry Norm	X < .05	X < .09	X < .02	X < .03	X < .05	X < .08	X < .12	X < .03
Yellow Range	.05 < X < .09	.09 < X < .15	.02 < X < .04	.03 < X < .05	.05 < X < .09	.08 < X > .14	.12 < X < .22	.03 < X < .05
Red Range	X > .09	X > .15	X > .04	X > .05	X > .09	X > .14	X > .22	X > .05
A-300/CF6								
Average (X)	0.05	0.12	0.05	0.06	0.03	0	0.05	0
Standard Dev.	0.09	0.09	0.1	0.08	0.06	0	0.11	0
Industry Norm	X < .14	X < .21	X < .15	X < .14	X < .09	0	X < .16	0
Yellow Range	.14 < X < .23	.21 < X < .30	.15 < X < .25	.14 < X < .22	.09 < X < .15	0	.16 < X < .27	0
Red Range	X > .23	X > .30	X > .25	X > .22	X > .15	0	X > .27	0

TABLE 3: IN-FLIGHT SHUTDOWN CALCULATIONS (CONTINUED)

	JUN '89	JUL '89	AUG '89	SEP '89	OCT '89	NOV '89	DEC '89	JAN '90
B-727/JT8D								
Average (X)	0.03	0.04	0.02	0.02	0.02	0.01	0.02	0.02
Standard Dev.	0.07	0.1	0.06	0.04	0.05	0.02	0.05	0.05
Industry Norm	X < .10	X < .14	X < .08	X < .06	X < .07	X < .03	X < .07	X < .07
Yellow Range	.10 < X < .17	.14 < X < .24	.08 < X < .14	.06 < X < .10	.07 < X < .12	.03 < X < .05	.07 < X < .12	.07 < X < .12
Red Range	X > .17	X > .24	X > .14	X > .10	X > .12	X > .05	X > .12	X > .12
B-737/JT8D								
Average (X)	0.02	0.01	0	0.02	0.01	0.02	0.03	0
Standard Dev.	0.06	0.05	0.02	0.05	0.04	0.06	0.08	0.01
Industry Norm	X < .08	X < .06	X < .02	X < .07	X < .05	X < .08	X < .11	X < .01
Yellow Range	.08 < X < .14	.06 < X < .11	.02 < X < .04	.07 < X < .12	.05 < X < .09	.08 < X < .14	.11 < X < .19	.01 < X < .02
Red Range	X > .14	X > .11	X > .04	X > .12	X > .09	X > .14	X > .19	X > .02
DC-9/JT8D								
Average (X)	0.01	0.01	0.02	0.01	0.01	0.01	0.02	0.01
Standard Dev.	0.02	0.02	0.06	0.03	0.02	0.02	0.06	0.05
Industry Norm	X < .03	X < .03	X < .08	X < .04	X < .03	X < .03	X < .08	X < .06
Yellow Range	.03< X < .05	.03 < X < .05	.08 < X < .14	.04 < X < .07	.03 < X < .05	.03 < X < .05	.08< X < .14	.06 < X < .11
Red Range	X > .05	X > .05	X > .14	X > .07	X > .05	X > .05	X > .14	X > .11
A-300/CF6								
Average (X)	0.05	0.04	0.06	0	0	0.07	0	0
Standard Dev.	0.1	0.08	0.11	0	0	0.1	0	0
Industry Norm	X < .15	X < .12	X < .17	0	0	X < .17	0	0
Yellow Range	.15 < X < .25	.12 < X < .20	.17 < X < .28	0	0	.17 < X < .27	0	0
Red Range	X > .25	X > .20	X > .28	0	0	X > .27	0	0

TABLE 3: IN-FLIGHT SHUTDOWN CALCULATIONS (CONTINUED)

	FEB '88	MAR '88	APR '88	MAY '88	JUN '88	JUL '88	AUG '88	SEPT '88
B-767/CF6								
Average (X)	0	0	0.01	0	0	0	0.02	0.02
Standard Dev.	0	0	0.03	0	0	0	0.03	0.03
Industry Norm	0	0	X < .04	0	0	0	X < .05	X < .05
Yellow Range	0	0	.04 < X < .07	0	0	0	.05 < X < .08	.05 < X < .08
Red Range	0	0	X > .07	0	0	0	X > .08	X > .08
DC-10/CF6								
Average (X)	0.15	0.03	0.06	0.09	0.04	0.04	0.08	0.02
Standard Dev.	0.27	0.06	0.12	0.17	0.14	0.09	0.13	0.04
Industry Norm	X < .42	X < .09	< .18	X < .26	X < .18	X < .13	X < .21	X < .06
Yellow Range	.42 < X < .69	.09 < X < .15	.18 < X < .30	.26 < X < .43	.18 < X < .32	.13 < X < .22	.21 < X < .34	.06 < X < .10
Red Range	X > .69	X > .15	X > .30	X > .43	X > .32	X > .22	X > .34	X > .10
B-707/JT3D								
Average (X)	0.13	0.02	0.1	0.02	0.04	0.09	0.08	0.1
Standard Dev.	0.31	0.07	0.23	0.06	0.12	0.19	0.27	0.2
Industry Norm	X < .44	X < .09	X < .33	X < .08	X < .16	X < .28	X < .35	X < .30
Yellow Range	.44 < X < .75	.09 < X < .16	.33 < X < .56	.08 < X < .14	.16 < X < .28	.28 < X < .47	.35 < X < .62	.30 < X < .50
Red Range	X > .75	X > .16	X > .56	X > .14	X > .28	X > .47	X > .62	X > .50
DC-8/JT3D								
Average (X)	0.05	0.17	0.17	0.12	0.02	0.03	0.06	0.06
Standard Dev.	0.11	0.32	0.42	0.35	0.1	0.08	0.14	0.16
Industry Norm	X < .16	X < .49	X < .59	X < .47	X < .12	X < .11	X < .20	X < .22
Yellow Range	.16 < X < .21	.49 < X < .81	.59 < X < 1.01	.47< .82	.12 < X < .22	.11 < X < .19	.20 < X < .34	.22 < X < .38
Red Range	X > .21	X > .81	X > 1.01	X > .82	X > .22	X > .19	X > .34	X > .38

TABLE 3: IN-FLIGHT SHUTDOWN CALCULATIONS (CONTINUED)

	OCT '88	NOV '88	DEC '88	JAN '89	FEB '89	MAR '89	APR '89	MAY '89
B-767/CF6								
Average (X)	0	0	0.06	0	0	0	0.02	0
Standard Dev.	0	0	0.13	0	0	0	0.04	0
Industry Norm	0	0	X < .19	0	0	0	X < .06	0
Yellow Range	0	0	.19 < X < .32	0	0	0	.06 < X < .10	0
Red Range	0	0	X > .32	0	0	0	X > .10	0
DC-10/CF6								
Average (X)	0	0.01	0.02	0.04	0.05	0.02	0.05	0.04
Standard Dev.	0.01	0.03	0.04	0.05	0.15	0.04	0.08	0.05
Industry Norm	X < .01	X < .04	X < .06	X < .09	X < .20	X < .06	X < .13	X < .09
Yellow Range	.01 < X < .02	.04 < X < .07	.06 < X < .10	.09 < X < .14	.20 < X < .35	.06 < X < .10	.13 < X < .21	.09 < X < .14
Red Range	X > .02	X > .07	X > .10	X > .14	X > .35	X > .10	X > .21	X > .14
B-707/JT3D								
Average (X)	0.05	0	0.13	0	0.02	0.02	0	0.02
Standard Dev.	0.14	0	0.29	0	0.07	0.06	0	0.06
Industry Norm	X < .19	0	X < .42	0	X < .09	X < .08	0	X < .08
Yellow Range	.19 < X < .33	0	.42 < X < .71	0	.09 < X < .16	.08 < X < .14	0	.08 < X < .14
Red Range	X > .33	0	X > .71	0	X > .16	X > .14	0	X > .14
DC-8/JT3D								
Average (X)	0.03	0.22	0.08	0.02	0.12	0.04	0.07	0.05
Standard Dev.	0.1	0.3	0.21	0.06	0.34	0.08	0.19	0.13
Industry Norm	X < .13	X < .52	X < .29	X < .08	X < .46	X < .12	X < .26	X < .18
Yellow Range	.13 < X < .23	.52 < X < .82	.29 < X < .50	.08 < X < .14	.46 < X < .80	.12 < X < .20	.26 < X < .45	.18 < X < .31
Red Range	X > .23	X > .82	X > .50	X > .14	X > .80	X > .20	X > .45	X > .31

TABLE 3: IN-FLIGHT SHUTDOWN CALCULATIONS (CONTINUED)

	JUN '89	JUL '89	AUG '89	SEP '89	OCT '89	NOV '89	DEC '89	JAN '90
B-767/CF6								
Average (X)	0	0	0.02	0	0.03	0	0.02	0
Standard Dev.	0	0	0.05	0	0.07	0	0.05	0
Industry Norm	0	0	X < .07	0	X < .10	0	X < .07	0
Yellow Range	0	0	.07< X < .12	0	.10 < X < .17	0	.07 < X < .12	0
Red Range	0	0	X > .12	0	X > .17	0	X > .12	0
B-DC-10/CF6								
Average (X)	0.01	0.05	0.01	0.05	0.03	0.04	0.01	0.05
Standard Dev.	0.03	0.06	0.03	0.07	0.05	0.04	0.02	0.07
Industry Norm	X < .04	X < .11	X < .04	X < .12	X < .08	X < .08	X < .03	X < .12
Yellow Range	.04 < X < .07	.11 < X < .17	.04 < X < .07	.12 < X < .19	.08 < X < .13	.08 < X < .12	.03 < X < .05	.12 < X < .19
Red Range	X > .07	X > .17	X > .07	X > .19	X > .13	X > .12	X > .05	X > .19
B-707/JT3D								
Average (X)	0	0.02	0.03	0	0.07	0.13	0.09	0.04
Standard Dev.	0	0.07	0.1	0	0.16	0.25	0.16	0.12
Industry Norm	0	X < .09	X < .13	0	X < .23	X < .38	X < .25	X < .16
Yellow Range	0	.09 < X < .16	.13 < X < .23	0	.23 < X < .39	.38 < X < .63	.25 < X < .41	.16 < X < .28
Red Range	0	X > .16	X > .23	0	X > .39	X > .63	X > .41	X > .28
DC-8/JT3D								
Average (X)	0.08	0.07	0.13	0.06	0.06	0.13	0.1	0.09
Standard Dev.	0.16	0.15	0.18	0.13	0.14	0.28	0.17	0.19
Industry Norm	X < .24	X < .22	X < 31	X < .19	X < .20	X < .41	X < .27	X < .28
Yellow Range	.24 < X < .40	.22 < X < .37	.31 < X < .49	.19 < X < .32	.20 < X < .34	.41 < X < .69	.27 < X < .44	.28 < X < .47
Red Range	X > .40	X > .37	X > .49	X > .32	X > .34	X > .69	X > .44	X > .47

TABLE 4: ENGINE REMOVAL CALCULATIONS

	FEB '88	MAR '88	APR '88	MAY '88	JUN '88	JUL '88	AUG '88	SEPT '88
B-727/JT8D								
Average (X)	0.15	0.12	0.08	0.15	0.12	0.17	0.14	0.1
Standard Dev.	0.37	0.16	0.14	0.25	0.17	0.25	0.19	0.2
Industry Norm	X < .52	X < .28	X < .22	X < .40	X < .29	X < .42	X < .33	X < .30
Yellow Range	.52 < X < .93	.28 < X < .44	.22 < X < .36	.40 < X < .65	.29 < X < .46	.42 < X < .67	.33< X < .52	.30< X < .50
Red Range	X > .93	X > .44	X > .36	X > .65	X > .46	X > .67	X > .52	X > .50
B-737/JT8D								
Average (X)	0.16	0.16	0.1	0.09	0.12	0.08	0.11	0.12
Standard Dev.	0.24	0.25	0.14	0.17	0.19	0.17	0.17	0.18
Industry Norm	X < .40	X < .41	X < .24	X < .26	X < .31	X < .25	X < .28	X < .30
Yellow Range	.40 < X < .64	.41 < X < .66	.24 < X < .38	.26 < X < .43	.31< X < .50	.25 < X < .42	.28 < X < .45	.30 < X < .48
Red Range	X > .64	X > .66	X > .38	X > .43	X > .50	X > .42	X > .45	X > .48
DC-9/JT8D								
Average (X)	0.12	0.19	0.14	0.14	0.21	0.1	0.14	0.14
Standard Dev.	0.16	0.23	0.16	0.2	0.29	0.11	0.16	0.16
Industry Norm	X < .28	X < .42	X < .30	X < .34	X < .50	X < .21	X < .30	X < .30
Yellow Range	.28 < X < .44	.42 < X < .65	.30 < X < .46	.34 < X < .54	.50 < X < .79	.21 < X < .32	.30 < X < .46	.30 < X < .46
Red Range	X > .44	X > .65	X > .46	X > .54	X > .79	X > .32	X > .46	X > .46
A-300/CF6								
Average (X)	0.31	0.42	0.26	0.39	0.26	0.37	0.22	0.33
Standard Dev.	0.11	0.11	0.22	0.46	0.23	0.3	0.21	0.29
Industry Norm	X < .42	X < .53	X < .48	X < .85	X < .49	X < .67	X < .43	X < .62
Yellow Range	.42 < X < .53	.53 < X < .64	.48 < X < .70	.85 < X < 1.31	.49 < X < .72	.67 < X < .97	.43 < X < .64	.62 < X < .91
Red Range	X > .53	X > .64	X > .70	X > 1.31	X > .72	X > .97	X > .64	X > .91

TABLE 4: ENGINE REMOVAL CALCULATIONS (CONTINUED)

	OCT '88	NOV '88	DEC '88	JAN '89	FEB '89	MAR '89	APR '89	MAY '89
B-727/JT8D								
Average (X)	0.1	0.07	0.07	0.07	0.12	0.1	0.15	0.08
Standard Dev.	0.2	0.11	0.12	0.14	0.2	0.13	0.25	0.09
Industry Norm	X < .30	X < .18	X < .19	X < .21	X < .32	X < .23	X < .40	X < .17
Yellow Range	.30 < X < .50	.18 < X < .29	.19 < X < .31	.21 < X < .35	.32 < X < .52	.23 < X < .36	.40 < X < .65	.17 < X < .26
Red Range	X > .50	X > .29	X > .31	X > .35	X > .52	X > .36	X > .65	X > .26
B-737/JT8D								
Average (X)	0.13	0.12	0.11	0.13	0.9	0.08	0.06	0.08
Standard Dev.	0.24	0.21	0.17	0.2	0.15	0.15	0.1	0.11
Industry Norm	X < .37	X < .33	X < .28	X < .33	X < .26	X < .23	X < .16	X < .19
Yellow Range	.37 < X < .61	.33 < X < .54	.28 < X < .45	.33 < X < .53	.26 < X < .41	.23 < X < .38	.16 < X < .26	.19 < X < .30
Red Range	X > .61	X > .54	X > .45	X > .53	X > .41	X > .38	X > .26	X > .30
DC-9/JT8D								
Average (X)	0.14	0.19	0.1	0.13	0.3	0.16	0.18	0.12
Standard Dev.	0.25	0.21	0.15	0.17	0.47	0.27	0.28	0.16
Industry Norm	X < .39	X < .40	X < .25	X < .30	X < .77	X < .43	X < .46	X < .28
Yellow Range	.39 < X < .64	.40 < X < .61	.21 < X < .40	.30 < X < .47	.77 < X < 1.24	.43 < X > .70	.46 < X < .74	.28< X < .44
Red Range	X > .64	X > .61	X > .40	X > .47	X > 1.24	X > .70	X > .74	X > .44
A-300/CF6								
Average (X)	0.23	0.44	0.38	0.28	0.53	0.73	0.15	0.4
Standard Dev.	0.28	0.22	0.21	0.31	0.41	0.68	0.1	0.41
Industry Norm	X < .51	X < .66	X < .59	X < .94	X < .94	X < 1.41	X < .25	X < .81
Yellow Range	.51 < X < .79	.66 < X < .88	.59 < X < .80	.59 < X < .90	.94 < X < 1.35	1.41 < X < 2.09	.25 < X < .35	81 < X < 1.22
Red Range	X >.79	X > .88	X > .80	X > .90	X > 1.35	X > 2.09	X > .35	X > 1.22

TABLE 4: ENGINE REMOVAL CALCULATIONS (CONTINUED)

	JUN '89	JUL '89	AUG '89	SEP '89	OCT '89	NOV '89	DEC '89	JAN '90
B-727/JT8D								
Average (X)	0.11	0.16	0.12	0.07	0.09	0.07	0.06	0.1
Standard Dev.	0.17	0.21	0.19	0.11	0.15	0.09	0.11	0.16
Industry Norm	X < .28	X < .37	X < .31	X < .18	X < .24	X < .16	X < .17	X < .26
Yellow Range	.28 < X < .45	.37< X < .58	.31 < X < .50	.18 < X < .29	.24 < X < .39	.16 < X < .25	.17 < X < .28	.26 < X < .42
Red Range	X > .45	X > .58	X > .50	X > .29	X > .39	X > .25	X > .28	X > .42
B-737/JT8D								
Average (X)	0.15	0.08	0.12	0.08	0.06	0.05	0.08	0.13
Standard Dev.	0.22	0.13	0.16	0.13	0.11	0.09	0.1	0.18
Industry Norm	X < .37	X < .21	X < .28	X < .21	X < .17	X < .14	X < .18	X < .31
Yellow Range	.37 < X < .59	.21 < X < .34	.28 < X < .44	.21 < X < .34	.17 < X < .28	.14 < X < .23	.18 < X < .28	.31 < X < .49
Red Range	X > .59	X > .34	X > .44	X > .34	X > .28	X > .23	X > .28	X > .49
DC-9/JT8D								
Average (X)	0.1	0.11	0.19	0.14	0.1	0.1	0.12	0.12
Standard Dev.	0.12	0.15	0.25	0.19	0.14	0.12	0.15	0.13
Industry Norm	X < .22	X < .26	X < .44	X < .33	X < .24	X < .22	X < .27	X < .25
Yellow Range	.22 < X < .34	.26 < X < .41	.44 < X < .69	.33 < X < .52	.24 < X < .38	.22 < X < .34	.27< X < .42	.25 < X < .38
Red Range	X > .34	X > .41	X > .69	X > .52	X > .38	X > .34	X > .42	X > .38
A-300/CF6								
Average (X)	0.55	0.19	0.3	0.25	0.25	0.33	0.29	0.35
Standard Dev.	0.59	0.25	0.15	0.13	0.13	0.27	0.11	0.15
Industry Norm	X < 1.14	X < .44	X < .45	X < .38	X < .38	X < .60	X < .40	X < .50
Yellow Range	1.14 < X < 1.73	.44 < X < .69	.45 < X < .60	.38 < X < .51	.38 < X < .51	.60 < X < .87	.40 < X < .51	.50 < X < .65
Red Range	X > 1.73	X > .69	X > .60	X > .51	X > .51	X > .87	X > .51	X > .65

TABLE 4: ENGINE REMOVAL CALCULATIONS (CONTINUED)

	FEB '88	MAR '88	APR '88	MAY '88	JUN '88	JUL '88	AUG '88	SEPT '88
B-767/CF6								
Average (X)	0.14	0.14	0.06	0.09	0.08	0.15	0.09	0.1
Standard Dev.	0.18	0.18	0.07	0.1	0.1	0.11	0.08	0.13
Industry Norm	X < .32	X < .32	X < .13	X < .19	X < .18	X < .26	X < .17	X < .23
Yellow Range	.32 < X < .50	.32 < X < .50	.13< X < .20	.19 < X < .29	.18 < X < .28	.26 < X < .37	.17 < X < .25	.23 < X < .36
Red Range	X > .50	X > .50	X > .20	X > .29	X > .28	X > .37	X > .25	X > .36
DC-10/CF6								
Average (X)	0.23	0.25	0.17	0.29	0.22	0.2	0.31	0.18
Standard Dev.	0.16	0.23	0.15	0.42	0.25	0.21	0.29	0.26
Industry Norm	X < .39	X < .48	< .32	X < .71	X < .47	X < .41	X < .60	X < .44
Yellow Range	.39 < X < .55	.48 < X < .71	.32 < X < .47	.71 < X < 1.13	.47< X < .72	.41 < X < .62	.60 < X < .89	.44 < X < .70
Red Range	X > .55	X > .71	X > .47	X > 1.13	X > .72	X > .62	X > .89	X > .70
B-707/JT3D								
Average (X)	0.21	0.11	0.06	0.04	0.04	0.09	0.29	0.05
Standard Dev.	0.48	0.21	0.17	0.15	0.12	0.19	0.55	0.16
Industry Norm	X < .69	X < .32	X < .23	X < .19	X < .16	X < .28	X < .84	X < .21
Yellow Range	.69 < X < 1.17	.32 < X < .53	.23 < X < .40	.19 < X < .34	.16 < X < .28	.28 < X < .47	.84 < X < 1.39	.21 < X < .37
Red Range	X > 1.17	X > .53	X > .40	X > .34	X > .28	X > .47	X > 1.39	X > .37
DC-8/JT3D								
Average (X)	0.09	0.17	0.17	0.2	0.05	0.11	0.08	0.1
Standard Dev.	0.2	0.29	0.27	0.32	0.12	0.08	0.14	0.18
Industry Norm	X < .29	X < .46	X < .44	X < .52	X < .17	X < .31	X < .22	X < .28
Yellow Range	.29 < X < .49	.46 < X < .75	.44 < X < .71	.52 < X < .84	.17 < X < .29	.31 < X < .51	.22 < X < .36	.28 < X < .46
Red Range	X > .49	X > .75	X > .71	X > .84	X > .29	X > .51	X > .36	X > .38

TABLE 4: ENGINE REMOVAL CALCULATIONS (CONTINUED)

	OCT '88	NOV '88	DEC '88	JAN '89	FEB '89	MAR '89	APR '89	MAY '89
B-767/CF6								
Average (X)	0.15	0.09	0.15	0.17	0.17	0.08	0.31	0.12
Standard Dev.	0.15	0.11	0.11	0.13	0.07	0.08	0.3	0.18
Industry Norm	X < .30	X < .20	X < .26	X < .30	X < .24	X < .16	X < .61	X < .30
Yellow Range	.30 < X < .45	.20 < X < .31	.26 < X < .37	.30 < X < .43	.24 < X < .31	.16 < X < .24	.61 < X < .91	.30 < X < .48
Red Range	X > .45	X > .31	X > .37	X > .43	X > .31	X > .24	X > .91	X > .48
DC-10/CF6								
Average (X)	0.09	0.21	0.21	0.08	0.23	0.29	0.24	0.13
Standard Dev.	0.12	0.22	0.23	0.11	0.26	0.42	0.3	0.15
Industry Norm	X < .21	X < .43	X < .44	X < .19	X < .49	X < .71	X < .54	X < .28
Yellow Range	.21 < X < .33	.43 < X < .65	.44 < X < .67	.19 < X < .30	.49 < X < .75	.71 < X < 1.13	.54 < X < .84	.28 < X < .43
Red Range	X > .33	X > .65	X > .67	X > .30	X > .75	X > 1.13	X > .84	X > .43
B-707/JT3D								
Average (X)	0.05	0.09	0.1	0.04	0.09	0.02	0.02	0.14
Standard Dev.	0.14	0.25	0.23	0.1	0.28	0.06	0.06	0.31
Industry Norm	X < .19	X < .34	X < .33	X < .14	X < .37	X < .08	X < .08	X < .45
Yellow Range	.19 < X < .33	.34 < X < .59	.33 < X < .56	.14 < X < .24	.37 < X < .65	.08 < X < .14	.08 < X < .14	.45 < X < .76
Red Range	X > .33	X > .59	X > .56	X > .24	X > .65	X > .14	X > .14	X > .76
DC-8/JT3D								
Average (X)	0.1	0.16	0.14	0.11	0.16	0.11	0.06	0.11
Standard Dev.	0.26	0.22	0.26	0.3	0.37	0.21	0.12	0.19
Industry Norm	X < .36	X < .38	X < .40	X < .41	X < .53	X < .32	X < .18	X < .30
Yellow Range	.36 < X < .62	.38 < X < .60	.40 < X < .66	.41 < X < .71	.53 < X < .90	.32 < X < .53	.18 < X < .30	.30 < X < .49
Red Range	X > .62	X > .60	X > .66	X > .71	X > .90	X > .53	X > .30	X > .49

TABLE 4: ENGINE REMOVAL CALCULATIONS (CONTINUED)

	JUN '89	JUL '89	AUG '89	SEP '89	OCT '89	NOV '89	DEC '89	JAN '90
B-767/CF6								
Average (X)	0.09	0.24	0.3	0.24	0.19	0.13	0.02	0
Standard Dev.	0.07	0.14	0.19	0.17	0.16	0.14	0.08	0.12
Industry Norm	X < .16	X < .38	X < .49	X < .41	X < .35	X < .27	X < .20	< .22
Yellow Range	.16 < X < .25	.38 < X < .52	.49 < X < .68	.41 < X < .58	.35 < X < .51	.27 < X < .41	.20 < X < .28	.22 < X < .34
Red Range	X > .25	X > .52	X > .68	X > .58	X > .51	X > .41	X > .28	X > .34
B-DC-10/CF6								
Average (X)	0.18	0.25	0.1	0.19	0.15	0.07	0.1	0.16
Standard Dev.	0.2	0.2	0.1	0.16	0.14	0.08	0.09	0.17
Industry Norm	X < .38	X < .45	X < .20	X < .35	X < .29	X < .15	X < .19	X < .33
Yellow Range	.38 < X < .58	.45 < X < .65	.20 < X < .30	.35 < X < .51	.29 < X < .43	.15 < X < .23	.19 < X < .28	.33 < X < .50
Red Range	X > .58	X > .65	X > .30	X > .51	X > .43	X > .23	X > .28	X > .50
B-707/JT3D								
Average (X)	0	0.08	0.05	0.15	0.21	0.13	0.09	0.07
Standard Dev.	0	0.16	0.11	0.25	0.33	0.25	0.2	0.13
Industry Norm	0	X < .24	X < .16	X < .40	X < .54	X < .38	X < .29	X < .20
Yellow Range	0	.24 < X < .40	.16 < X < .27	.40 < X < .65	.54 < X < .87	.38 < X < .63	.29 < X < .49	.20 < X < .33
Red Range	0	X > .40	X > .27	X > .65	X > .87	X > .63	X > .49	X > .33
DC-8/JT3D								
Average (X)	0.02	0.06	0.09	0.07	0.09	0.13	0.12	0.07
Standard Dev.	0.06	0.14	0.15	0.16	0.13	0.28	0.21	0.16
Industry Norm	X < .08	X < .20	X < 26	X < .23	X < .22	X < .41	X < .33	X < .23
Yellow Range	.08 < X < .14	.20 < X < .34	.26 < X < .41	.23 < X < .39	.22< X < .35	.41 < X < .69	.33 < X < .54	.23 < X < .39
Red Range	X > .14	X > .34	X > .41	X > .39	X > .35	X > .69	X > .54	X > .39

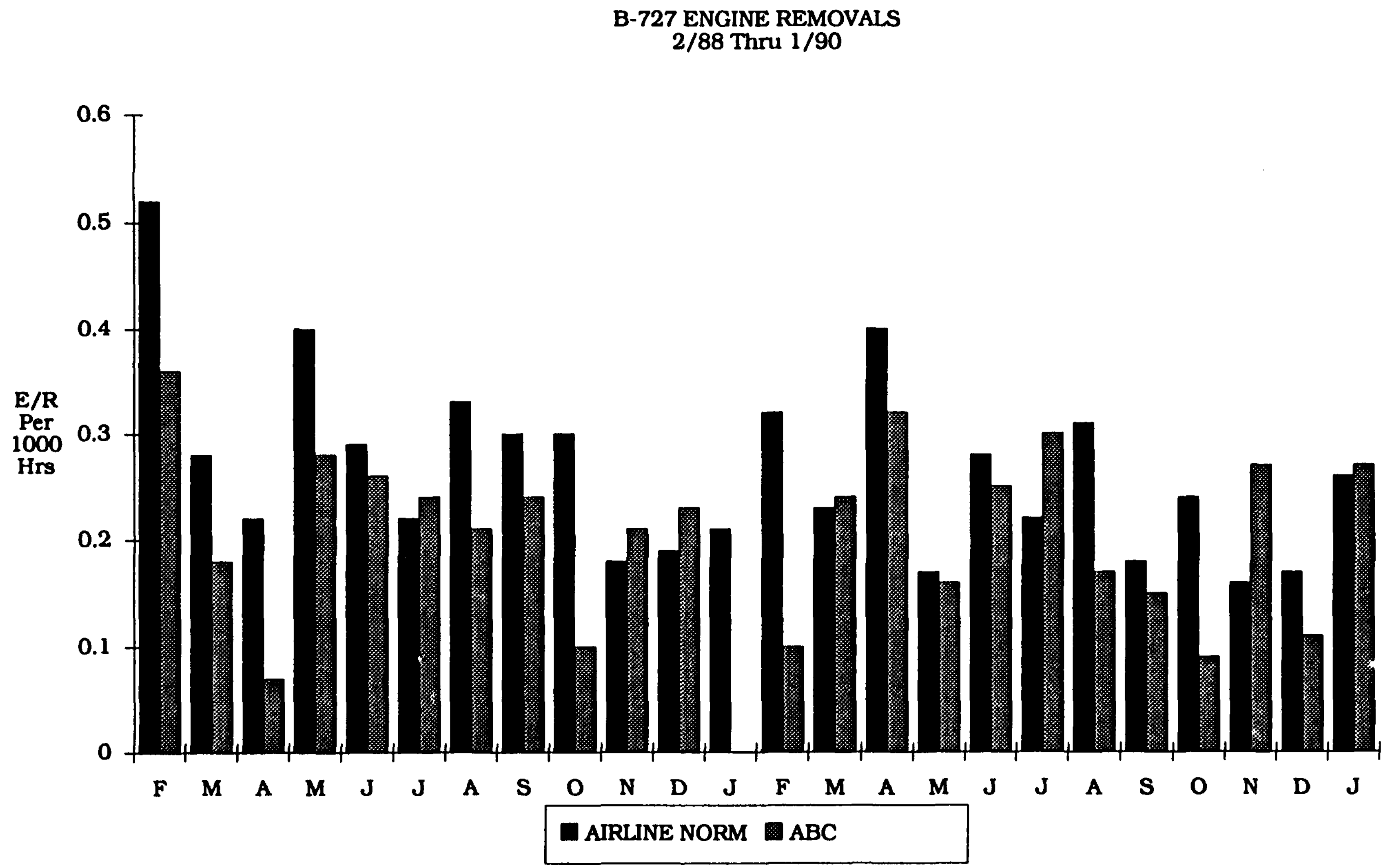


FIGURE 1 - SAMPLE DATA COMPARING AIRLINE ABC TO THE REST OF THE INDUSTRY FOR B-727 JT8D UNSCHEDULED ENGINE REMOVAL RATES.

B-727 ENGINE INFLIGHT SHUTDOWN
2/88 Thru 1/90

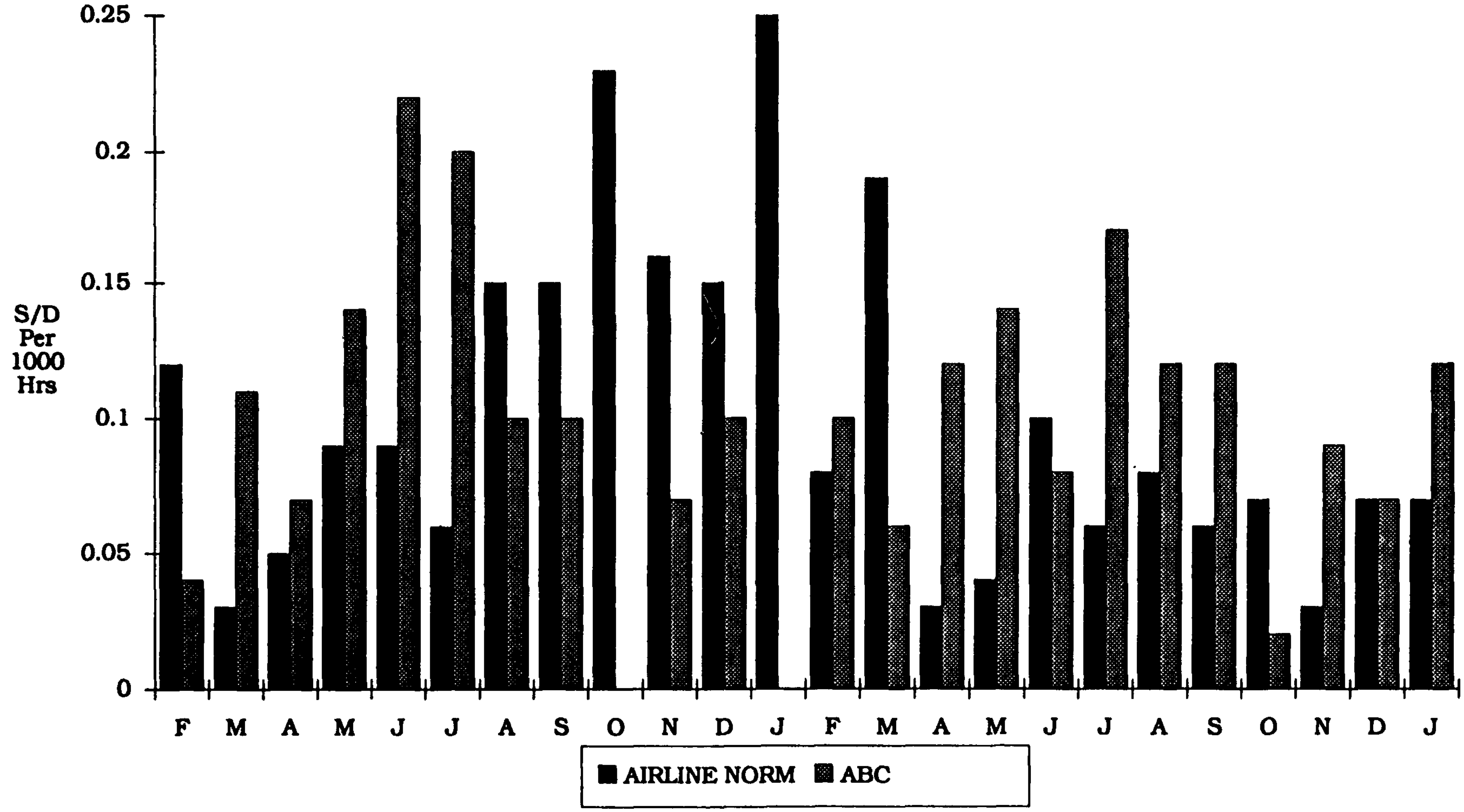


FIGURE 2 - SAMPLE DATA COMPARING AIRLINE ABC TO THE REST OF THE INDUSTRY FOR B-727 JT8D IN-FLIGHT ENGINE SHUTDOWN RATES.

TABLE 5: B-727/JT8D AIRLINE MACRO SCAN

Ranking of masked airlines operating B-727 and JT8D which experienced higher than normal in-flight shutdowns and engine removals				
AIRLINE	**% In-Flight Shutdown Exceedance**	**Ranking of Shutdown Exceedance**	**% Engine Removal Exceedance**	**Ranking of Engine Removal Exceedance**
OPO	62.50%	1	100.00%	1
ABC	58.30%	2	29.00%	11
GGA	25.00%	4	22.80%	14
RAB	20.80%	8	25.00%	9
DDA	20.70%	10	27.80%	7
BKB	20.60%	11	24.90%	12
FFF	18.50%	12	37.50%	4
GHI	18.50%	13	23.80%	13
XYZ	16.60%	14	19.30%	19
CTA	12.50%	17	26.90%	8
PPP	12.50%	18	16.60%	21
FPC	20.80%	9	4.00%	26

TABLE 6: B-737/JT8D AIRLINE MACRO SCAN

Ranking of masked airlines operating B-737/JT8D which experienced higher than normal in-flight shutdowns and engine removals				
AIRLINE	**% In-Flight Shutdown Exceedance**	**Ranking of Shutdown Exceedance**	**% Engine Removal Exceedance**	**Ranking of Engine Removal Exceedance**
CTA	25.00%	1	51.90%	1
RAB	22.80%	3	26.30%	3
NNN	24.90%	2	18.60%	5
ABC	20.80%	4	16.60%	7
MNO	20.80%	5	16.60%	8
GGA	16.60%	6	20.80%	4
FPC	16.60%	7	10.30%	12
WWW	14.50%	8	13.80%	11
GHI	12.50%	9	15.20%	10
PVK	12.50%	11	29.00%	2

TABLE 7: DC-9/JT8D AIRLINE MACRO SCAN

Ranking of masked airlines operating DC-9/JT8D which experienced higher than normal in-flight shutdowns and engine removals				
AIRLINE	**% In-Flight Shutdown Exceedance**	**Ranking of Shutdown Exceedance**	**% Engine Removal Exceedance**	**Ranking of Engine Removal Exceedance**
CTA	33.30%	1	45.80%	2
BKB	14.50%	3	16.60%	8
GGA	14.40%	4	17.90%	7
DDD	12.30%	7	43.60%	3
XYZ	15.20%	2	6.00%	15
FPC	12.40%	5	12.50%	11
LWZ	12.40%	6	20.70%	6

TABLE 8: A-300/CF6 AIRLINE MACRO SCAN

Ranking of masked airlines operating A-300/CF6 which experienced higher than normal in-flight shutdowns and engine removals				
AIRLINE	**% In-Flight Shutdown Exceedance**	**Ranking of Shutdown Exceedance**	**% Engine Removal Exceedance**	**Ranking of Engine Removal Exceedance**
ABC	17.00%	1	17.00%	2
XYZ	13.00%	4	21.00%	1
DDA	17.00%	2	13.00%	3
CTA	13.00%	3	8.00%	4

TABLE 9: B-767/CF6 AIRLINE MACRO SCAN

Ranking of masked airlines operating B-767/CF6 which experienced higher than normal in-flight shutdowns and engine removals				
AIRLINE	**% In-Flight Shutdown Exceedance**	**Ranking of Shutdown Exceedance**	**% Engine Removal Exceedance**	**Ranking of Engine Removal Exceedance**
FPC	13.00%	1	29.00%	1
DDA	8.00%	2	25.00%	2
SSS	4.00%	3	4.00%	3

TABLE 10: DC-10/CF6 AIRLINE MACRO SCAN

Ranking of masked airlines operating DC-10/CF6 which experienced higher than normal in-flight shutdowns and engine removals				
AIRLINE	**% In-Flight Shutdown Exceedance**	**Ranking of Shutdown Exceedance**	**% Engine Removal Exceedance**	**Ranking of Engine Removal Exceedance**
DEF	23.00%	1	29.00%	2
RAB	23.00%	2	13.00%	5
CTA	14.50%	4	38.00%	1
DDA	15.70%	3	15.30%	4
TMR	10.50%	5	29.00%	3
XYZ	4.00%	6	13.00%	6

TABLE 11: B-707/JT3D AIRLINE MACRO SCAN

Ranking of masked airlines operating B-707/JT3D which experienced higher than normal in-flight shutdowns and engine removals				
AIRLINE	**% In-Flight Shutdown Exceedance**	**Ranking of Shutdown Exceedance**	**% Engine Removal Exceedance**	**Ranking of Engine Removal Exceedance**
UNS	50.00%	1	54.00%	1
MMM	46.00%	2	50.00%	2
ZZZ	8.00%	3	21.00%	3
VOI	4.00%	4	4.00%	5
TTT	4.00%	5	4.00%	6

TABLE 12: DC-8/JT3D AIRLINE MACRO SCAN

Ranking of masked airlines operating DC-8/JT3D which experienced higher than normal in-flight shutdowns and engine removals				
AIRLINE	**% In-Flight Shutdown Exceedance**	**Ranking of Shutdown Exceedance**	**% Engine Removal Exceedance**	**Ranking of Engine Removal Exceedance**
JJJ	50.00%	1	46.00%	2
RCW	29.00%	3	58.00%	1
XCU	31.00%	2	27.00%	3
YTA	25.00%	4	23.00%	5
YYY	25.00%	5	25.00%	4
ZOG	21.00%	6	17.00%	8
ANO	17.00%	7	21.00%	6
HHH	10.50%	9	15.00%	9

COMPONENT FAILURE RESULTS

Based on the results from the actuarial analysis, 10 airlines operating JT8D engines were further analyzed to identify which engine components caused the higher than normal shutdown and removal rates. The operators, analyzed by airframe, included eight operators of B-727, five operators of B-737 and five DC-9 operators. Note, that four operators were identified as having high exceedances while operating two of these airframes and two operators had high exceedances while operating JT8Ds on all three airframe models. Table 13 lists the masked airlines and their airframe models.

TABLE 13: MASKED AIRLINES OPERATING JT8D ENGINES WITH VARIOUS AIRFRAMES IDENTIFIED FOR COMPONENT PERFORMANCE ANALYSIS

Configuration of Performance Summary

B-727 / JT8D	B-737 / JT8D	DC-9 / JT8D
BKB	CTA	CTA
DDA	MNO	DDD
CTA	RAB	GGA
XYZ	GGA	XYZ
OPO	DDD	BKB
GGA		
ABC		
RAB		

TABLE 14: JT8D COMPONENT FAILURE TRENDS 1983 TO 1990

Data Obtained From Air Carriers Consistently Exceeding Engine Fleet Norm Of In-flight Shutdowns And Engine Removals

TOTAL FAILURES	FAILING COMPONENTS	NUMBER OF OCCURRENCES
39	BLEED AIR DUCTS AND VALVES	
	• 8th Stage Duct Cracking	4
	• 13th Stage Duct Cracking	14
	• Stuck Valve/Wired Open, Etc.	2
	• Other	19
64	MAIN BEARING	
	• #3 Main Bearing	32
	• #4 Main Bearing	7
	• Gearbox Bearings	10
	• Other	15
107	OIL SYSTEM FAILURES	
	• O-Ring Packing Cracked/Pinched	6
	• Bypass Switch/Line	8
	• Oil Pump	9
	• #6 Bearing Oil Tube Leak	16
	• Oil Line Leaks	1
	• Carbon Plugging of Oil Screen	5
	• Oil Screen Studs Stripped/ Pulled Loose	5
	• Oil Cap Unsecured	9
	• Oil Pressure Relief Valve	5
	• Other	43
13	ENGINE CASE FAILURE	
	• Fan	4
	• Intermediate	3
	• Diffuser	3
	• Other	3

TABLE 14. JT8D COMPONENT FAILURE TRENDS 1983 TO 1990 (CONTINUED)

128	FUEL SYSTEM FAILURES	
	• Fuel Control/Pump	54
	• Fuel Nozzle Coking	17
	• Fuel/Oil Heater	27
	- Housing	1
	- Gasket	2
	- Valve Wired Open	10
	• Other	17
189	FAN/COMPRESSOR/TURBINE BLADE/VANE FAILURES	
	• Fan Blades	14
	• Compressor Blades	34
	• Compressor Stators	8
	• Turbine Vanes	6
	- 1st Stage	
	- Other Stages	
	• Turbine Blades	85
	- 1st Stage	
	- 2nd Stage	
	- 3rd Stage	
	- 4th Stage	
	• Other	42

The SDR data base was searched for any engine component difficulties reported for these 10 airlines over the time period from 1983 through April 1990. Table14 summarizes these failures by general engine components.

Actual failures as submitted to the SDR data base by the 10 masked airlines are shown in appendix A.

The JT8D engine has an excellent reliability record and this actuarial review did not document any serious, safety-of-flight component failure patterns. However, this actuarial analysis did document some reliability problems, some of which are being worked by the prime engine manufacturer, requiring prompt installation of improved reliability configurations.

The JT8D engine SDR review identified two hard failure items in the #3 main bearing and the #4.5 to #6 bearing oil tube. Pratt & Whitney Aircraft (PWA) has been redesigning the #3 bearing for some time and testing improved configurations. An enhanced bearing should be available soon for airline installation. The #4.5 to #6 bearing oil tube cracking problem has some serious operational impacts. Typically, cracking in this tube permits vast oil leaks with resultant drop in oil pressure and rise in oil temperature. The engine is shut down during these occurrences and the flight diverted or returned to its originating station. A summary review of the failure history of this item shows the #4.5 to #6 bearing oil supply tube experienced cracking in the tube area as it fits through the engine exhaust case. The PWA initial response to this problem resulted in the use of a helical tube to stiffen the oil tube area and this fix was incorporated by Service Bulletin 4711. Unfortunately, the stiffened tube vibrated severely within the operating resonance of the engine itself and the incidents of cracking increased. Service Bulletin 5465 was released and it identified a different method of tube stiffening. This SB is available for incorporation. However, the SB 4711 configured oil tubes are still installed in the majority of the JT8D engine fleet and require some form of inspection to assure safe operation.

Several wear and tear failure patterns were observed during this actuarial review. The two most notable observations involved turbine blade failures and the failure of the 13th stage bleed air duct. The turbine blade failures were all reported as being contained failures and the random failure pattern among the four stages of the turbine appear to be the result of wear and tear of this rotating hot section component. The 13th stage bleed air duct failures were another one of those failures causing dramatic operational impacts. The hot bleed air exiting through the cracked duct walls or broken mounting flanges inevitably causes fire warning lights and/or bells to respond. The flight crew reaction to fire warning lights is to retard the throttle and check other engine parameters to verify the nature of the problem. Even if the analysis of engine performance data shows an engine fire has probably not occurred, the engine is normally shut down as a safety/economical precaution. The shut down logic is more prevalent on the three engine B-727 than it is on the twin engine DC-9 or B-737. No specific cracking pattern was discernable, although cracking in the mounting flange and holding bracket area was the dominant location. This item was not considered part of the engine and therefore the cracking problem is not being addressed by the prime engine manufacturer. The continued cracking in this bleed air duct requires an inspection procedure to be developed for follow-on operating assurance.

The SDR review also identified some diagnostic troubleshooting problems and some maintenance practices problems experienced by certain carriers. The most prevalent diagnostic troubleshooting observation involved engine fuel control and fuel pump removals for suspected malfunctions. However, the description of the maintenance actions taken as recorded in the SDR's indicated that two possible problems existed: (1) current instructions were vague in regard to diagnostic troubleshooting of these two fuel system items, or (2) existing diagnostic procedures were not being followed by maintenance personnel. There is also the possibility that a combination of the two causes exists.

The analysis also identified maintenance practices as contributing to in-flight shutdowns. Typical maintenance practices problems included: engine oil cap unsecured, fuel/oil heater valve wired open, oil screen studs pulled loose, and oil seals pinched. These practices often resulted in loss of power or loss of oil with the resultant engine shutdown and unscheduled engine removal. However, diagnostic troubleshooting problems and maintenance practices were not within the scope of this study effort and no further conclusions are offered on these subjects.

ENGINE CASE FAILURE ANALYSIS

Due to the concern of engine cases lacking assigned service lives, an increased emphasis to identify all engine case failures was pursued. To this effect, 24 JT8D engine case failures were identified from the period of 1983 to 1990. Note that this number includes the 13 engine case failures previously identified for the 10 airlines in table 13 plus all other US airlines operating JT8D engines for that same period.

A complete review, conducted with engineers at PWA, summarized and prioritized the criticality of these case failures. Discussion included background information on engine cases, case thicknesses, the manufacturing and welding processes, material properties, case failure modes, and current inspection methods. The two components of greatest concern in the 24 engine case failures were the weld seams along the flanges, and the drain boss welds. Both areas are currently inspected ultrasonically in the field.

For the weld seam inspection, a special carriage scanner was designed by PWA. The carriage scanner has rollers on each end of it and is used to hold the ultrasonic probe as it travels along the seam welds of the case. Water is gravity-fed from a bottle to the transducer as a couplant. The carriage scanner inspects the engine case flange a full 360 degrees. The test is calibrated using a specimen with an electrical discharge machined (EDM) notch in order to establish proper ultrasonic settings.

Prior to the test, calibration is performed on a known location on the engine case, ensuring proper placement and the use of sufficient couplant. Signal amplitude and locations are recorded by hand on a data sheet when crack indications are detected. Data are recorded along one line of scanning. The PWA engineers indicated that future engine case designs will eliminate the need for the weld along the flange.

The second inspection is of the outer combustor case drain boss weld areas. PWA's current inspection for cracks in these areas employs a transducer holder plate with two angle beam transducers in fixed positions to inspect an arc of about 80 degrees of the boss weld (shown in Figure 3). A calibration standard with two EDM notches is used to perform the pre-test calibration. The transducer plate, mounted on the end of a pole, enables the inspector to access the boss welds through the engine exhaust nozzle. Couplant is applied using a hypodermic tube. With the transducer in place, a trained inspector performs the inspection and interprets the test results from a portable ultrasonic instrument. The ultrasonic instrument is set so that a 0.5 inch crack in the weld area will produce a signal indication of 50 percent of the vertical screen height. It should be noted, however, that flaws or cracks existing in the weld away from the bolt holes may not be detected. Although PWA has recently redesigned the outer combustor case and eliminated the welds in the boss areas, it is believed that cases employing the welded drain bosses could be in use for the next decade. For this reason, the major thrust of the SAIC NDI effort concentrated on improving the outer combustor case drain boss weld inspection technique.

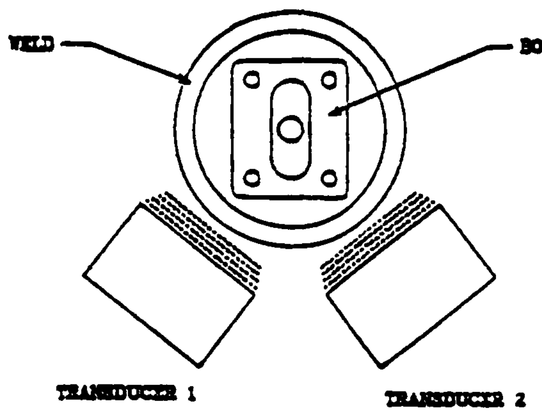


FIGURE 3 - PWA OUTER COMBUSTOR CASE INSPECTION DESIGN

Figure 4 shows the JT8D engine and the locations of the three drain bosses. A drain tube is attached to the forward drain boss at a slanted angle. The drain tube will cause restricted clearance in an approximately 20 degree region where no ultrasonic data can be taken.

<u>ULTRASONIC SCANNER DESIGN</u>

Preliminary laboratory work demonstrated the feasibility of developing an automated ultrasonic probe capable of surveying 240 degrees of the circumferential area around the drain welds. Close coordination was maintained during the development effort with the PWA engineers.

Although defects often occur in the weld near the rear bolt hole, defects can also exist at other areas in the weld. Several designs were considered by SAIC to inspect defects around the drain boss weld. One design used multiple angle-beam transducers, adjacent to each other. By multiplex pulsing each transducer, an ultrasonic signal would probe the weld area from each transducer location. This method is adequate for boss weld inspection, but for components of different shapes, multiple transducers would not be applicable. Since a new scanner was to be designed, applicability of the scanner to other engine case components was considered during the preliminary design stage.

The concept of the new scanner was to use a single transducer, carried by a motorized mechanism with remote control, to scan around the weld area. The transducer would increase step-wise radially, and move circumferentially around the center of the boss weld for a complete inspection. The transducer would have an appropriate beam angle, beam size, and frequency to provide best detectability and highest resolution.

The motorized boss weld scanner is driven by two 4-watt small DC motors and maintains position via an encoder system. A drawing of the scanner is shown in figure 5. The small motors are products of Maxon Precision Motors. The length of the rotating arm assembly of the scanner is 9.917 inches diameter of the boss plate, 9.042 inches and height of the scanner, 1.337 inches. Figure 6 illustrates the prototype JT8D boss weld scanner. For on-wing inspection, the scanner needs a pole to deliver the scanner from outside the engine, through the exhaust nozzle, to the boss welds inside.

A major component of the motorized scanner is a base plate containing a slot to position the scanner on the boss weld. A track chain is attached to the base plate which guides the arm assembly to rotate around the boss weld 240 degrees for circumferential scanning. The gear ratio for driving the arm assembly is 500:1 and the speed along the track is approximately 3 inches per second. The transducer holder, mounted on the arm, can move rapidly toward and away from the boss weld center, at increments of 0.020 inches per step. The scanning will occur once each radial increment, with the transducer moving around the boss weld along the track. The angle beam will inspect the entire thickness of the welded case when the transducer travels radially around the circumference of the weld.

Figure 7 shows a JT8D boss weld specimen and a calibration standard in which two EDM notches were placed. The EDM notches are 0.5 inches long and 20 mils deep. Figure 8 shows the prototype scanners installed for calibration in the laboratory. The prototype scanner, the motion control box, and the Ultra Image III™ equipment are presented in figure 9. Figure 10 shows Ultra Image results of the calibration standard inspected with the prototype scanner. The two EDM notches are clearly imaged. Appendix B contains the Ultra Image III™ specifications.

SCANNER DEMONSTRATION RESULTS

On March 22, 1991, a final demonstration of the prototype scanner was performed at PWA's laboratory in East Hartford. Figure 11 presents results on a sample containing four simulated flaws in a welded region. The locations of the four flaws are identified by the lower slice in the figure. Figure 12 shows the result of a sample with no flaws in the weld. There is no signal exceeding detectable level in this scan. It should be noted that if a flaw were to exist in the boss weld, distinctive signals would serve as indications similar to those in the calibration standard. Using the new Ultra Image IV™ software, figure 13 shows the results of the calibration standard test (figure 10) in the display. Appendix C contains a sample procedure of how the prototype scanner may be used in the field for drain boss inspection.

JT8D SERIES ENGINE BUILD GROUPS

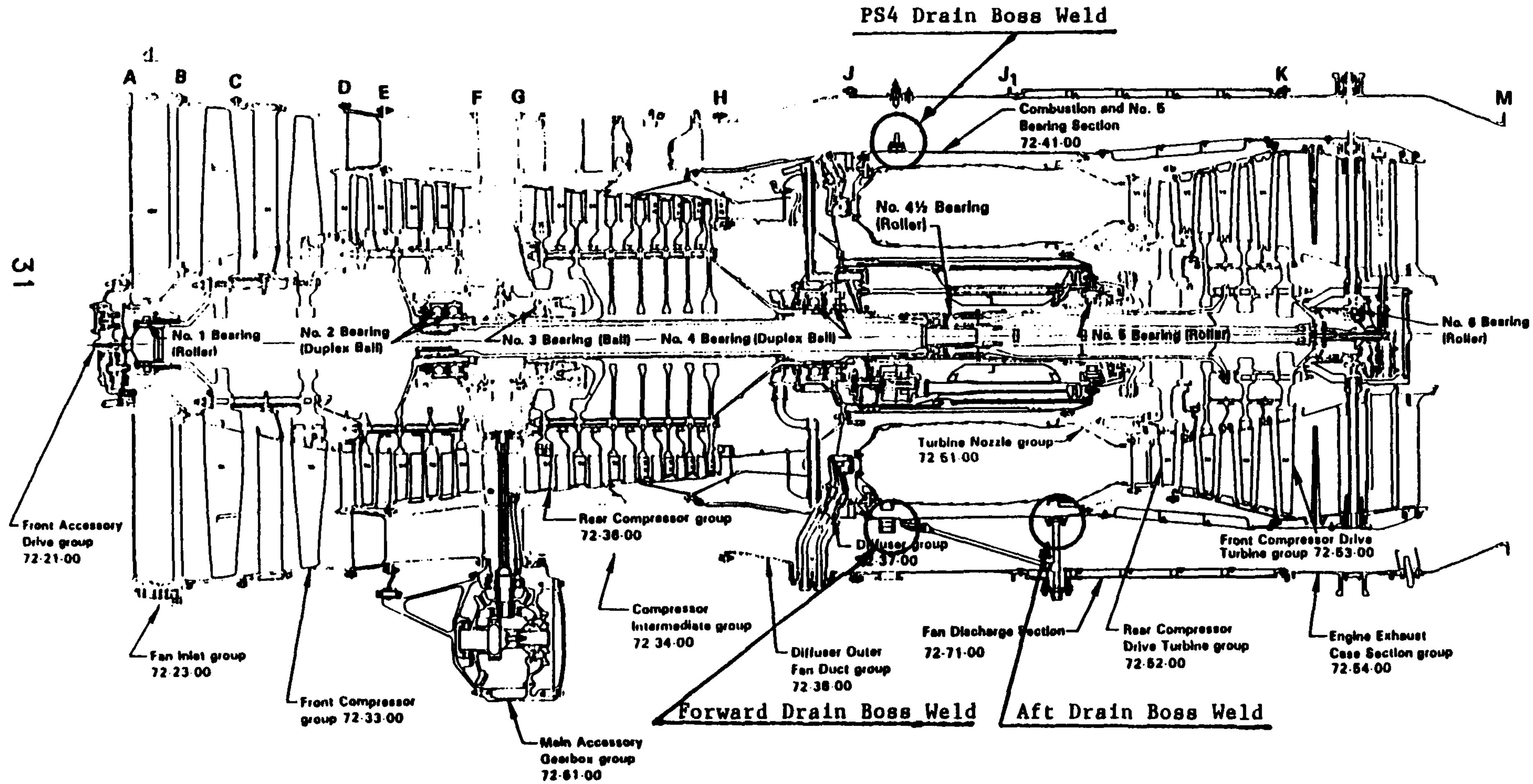


FIGURE 4 - SCHEMATICE OF JT8D ENGINE AND LOCATIONS OF THE DRAIN BOSS WELDS

UNITED TECHNOLOGIES PRATT & WHITNEY

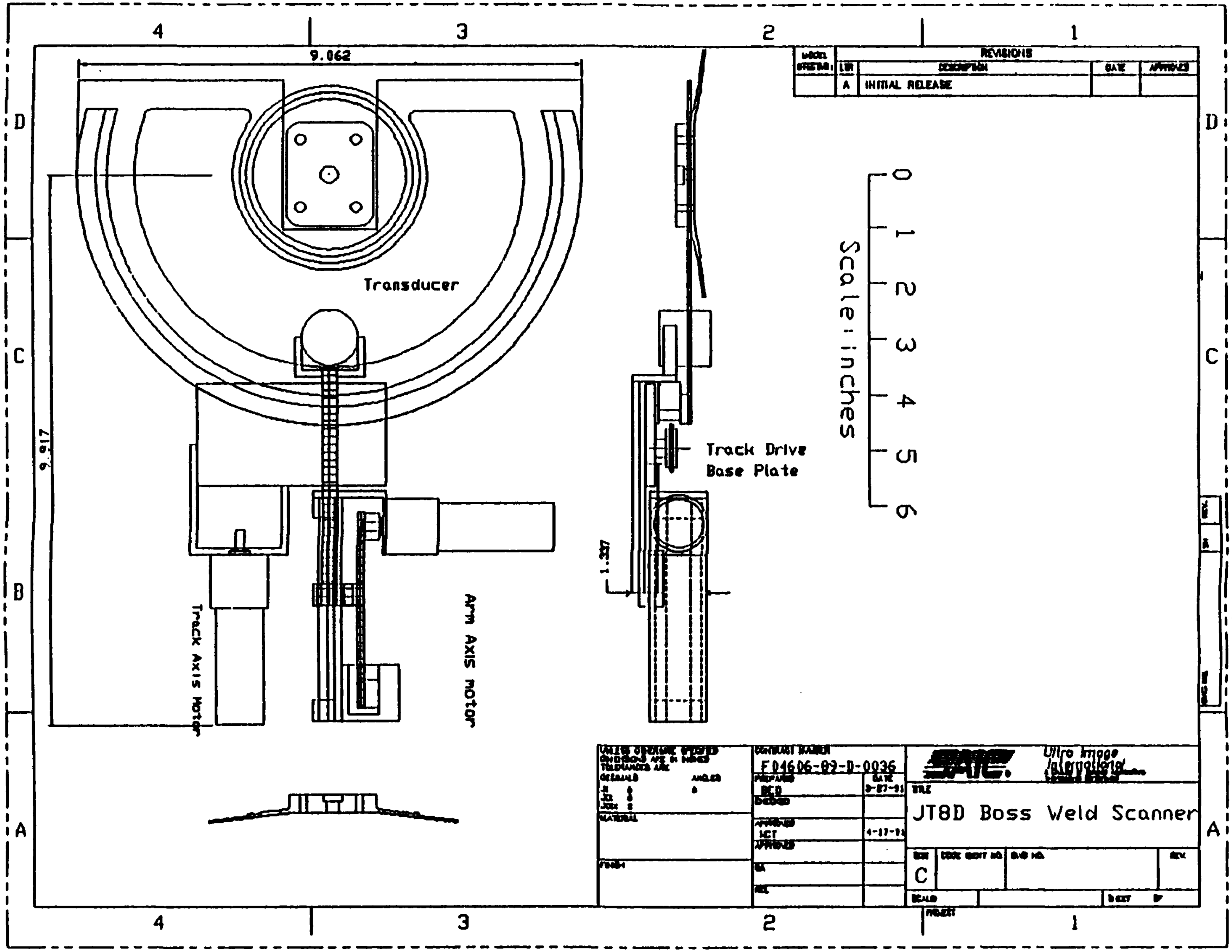


FIGURE 5 - SCHEMATIC OF PROTOTYPE JT8D MOTORIZED BOSS WELD SCANNER

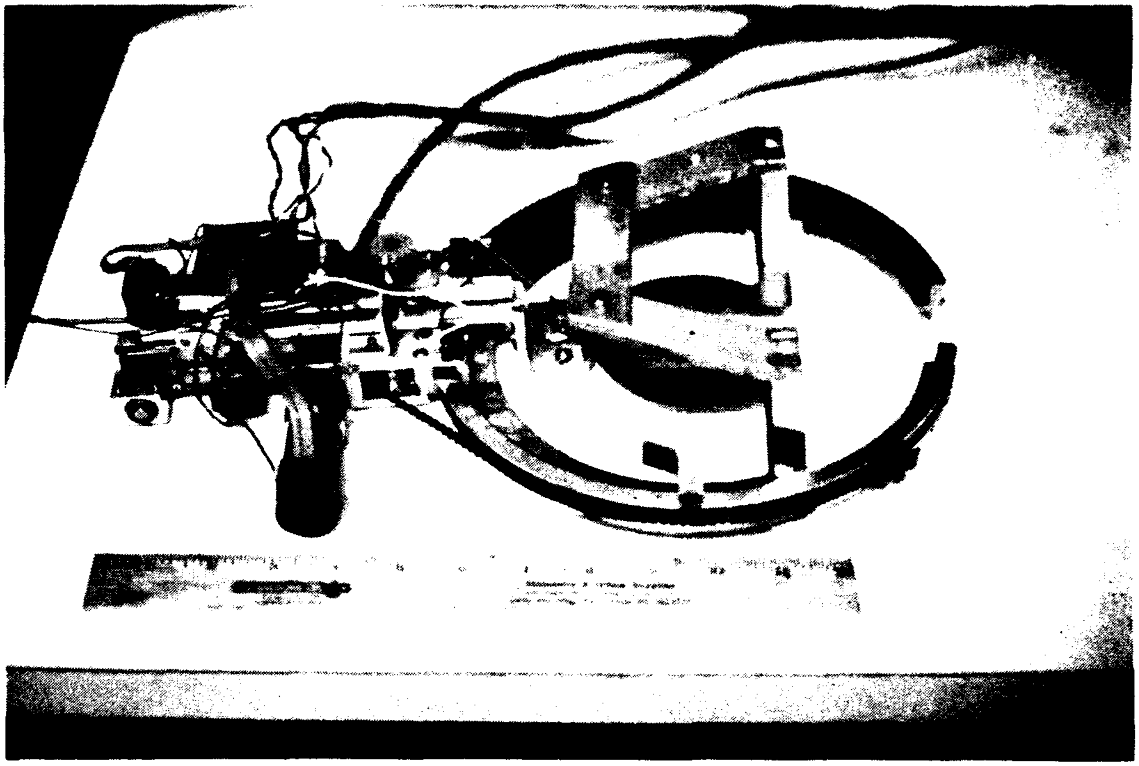


FIGURE 6 - PROTOTYPE MOTORIZED JT8D BOSS WELD SCANNER

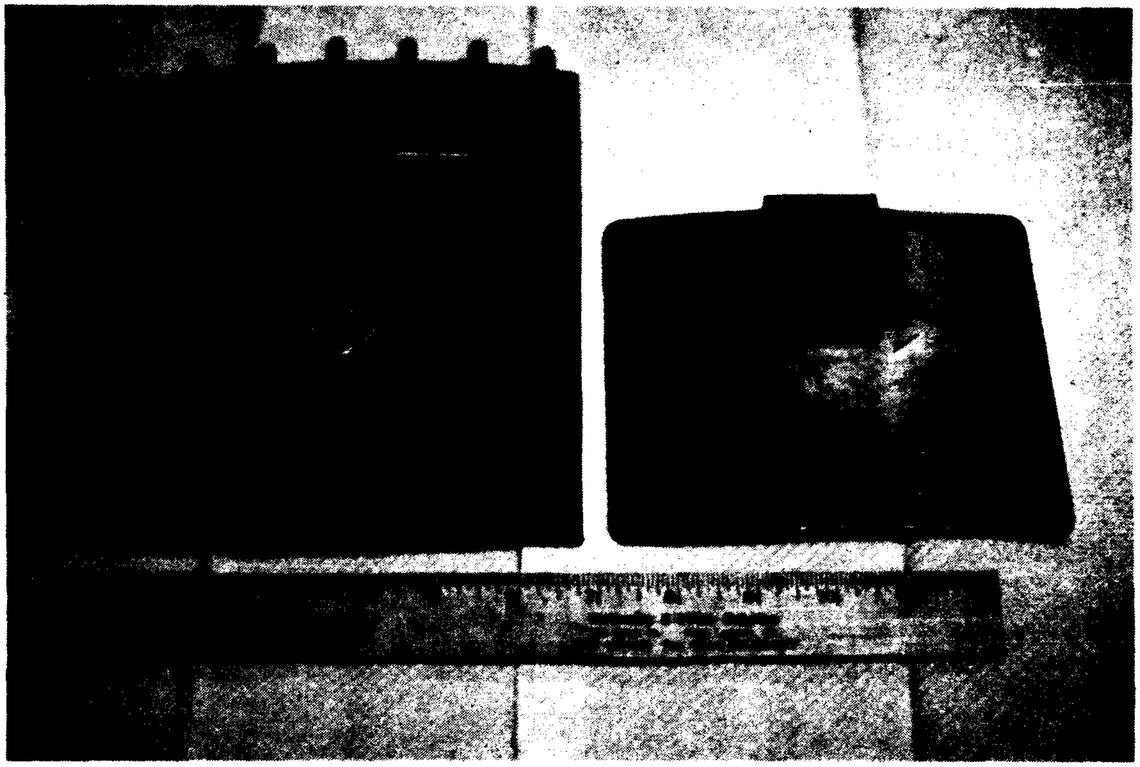


FIGURE 7 - JT8D BOSS WELD SPECIMEN (LEFT) AND CALIBRATION STANDARD (RIGHT)

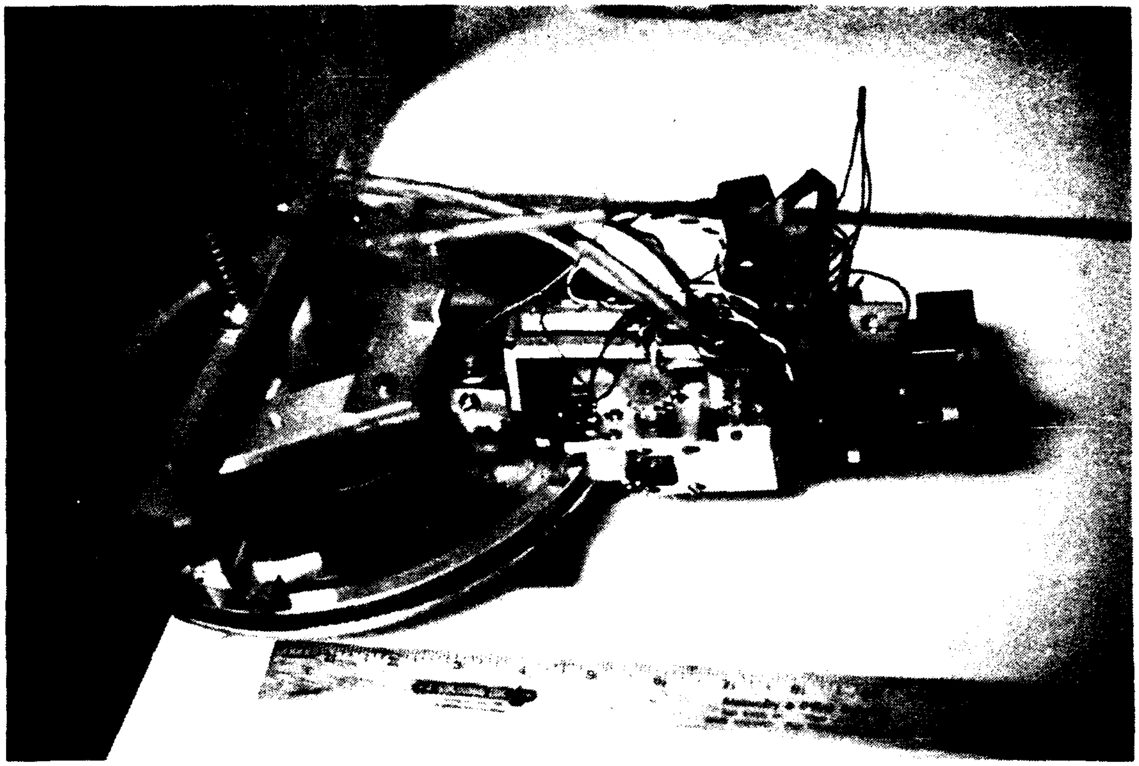


FIGURE 8 PROTOTYPE MOTORIZED JT8D BOSS WELD SCANNER ON CALIBRATION STANDARD

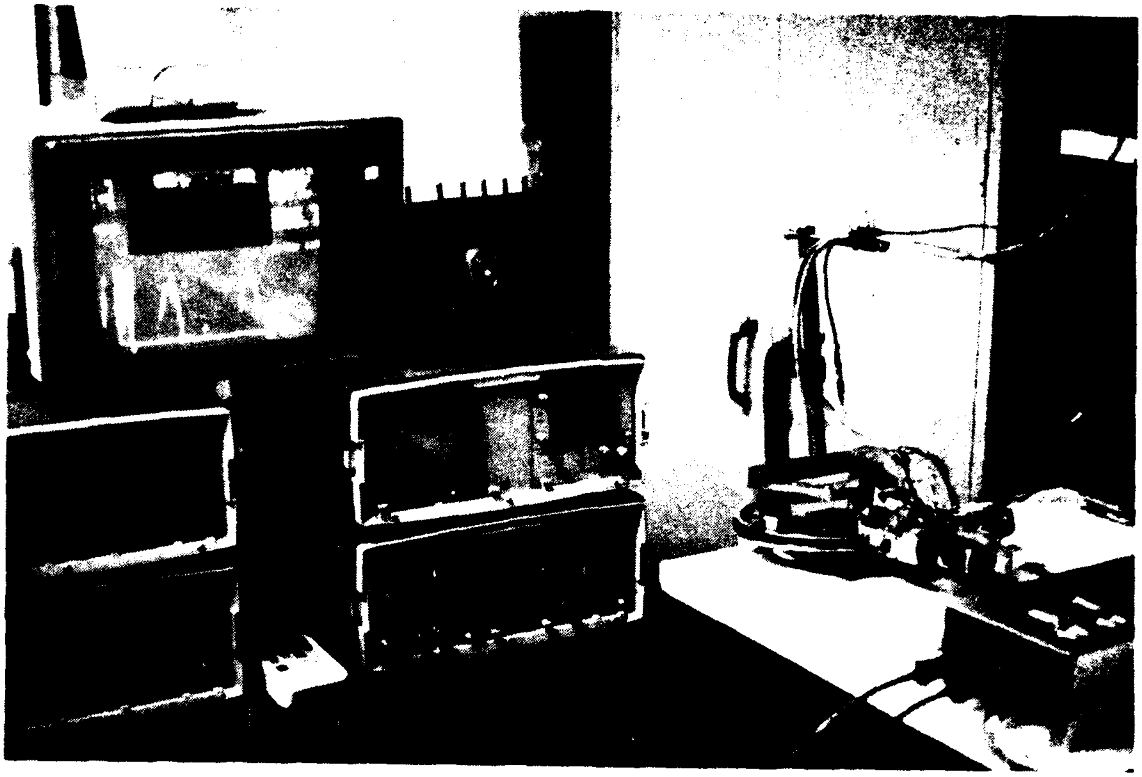


FIGURE 9 - ULTRA IMAGE III ™ WITH PROTOTYPE SCANNER

TESTING ON CALIBRATION STANDARD

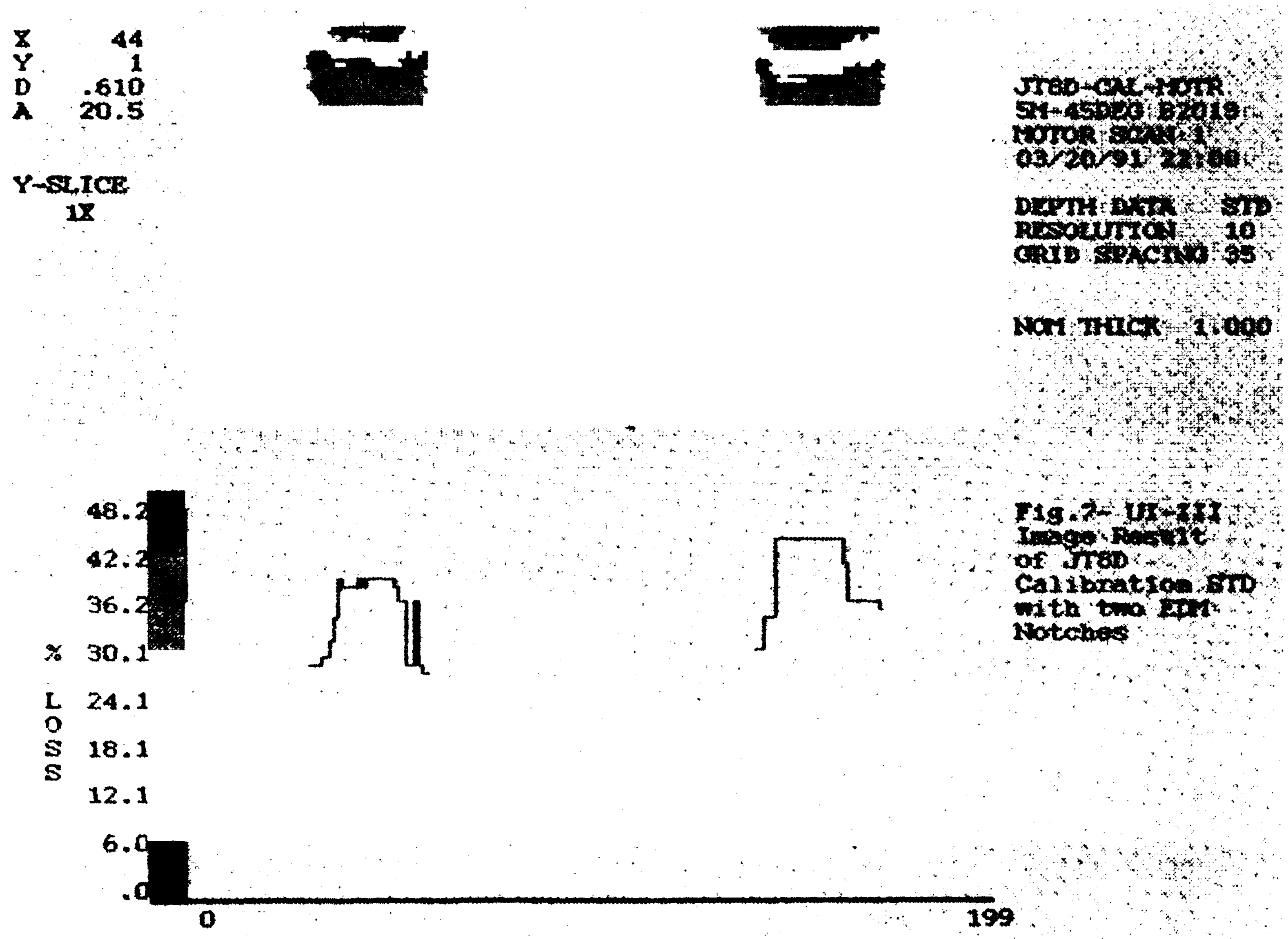


FIGURE 10 - ULTRA IMAGE III™ INSPECTION OF CALIBRATION STANDARD

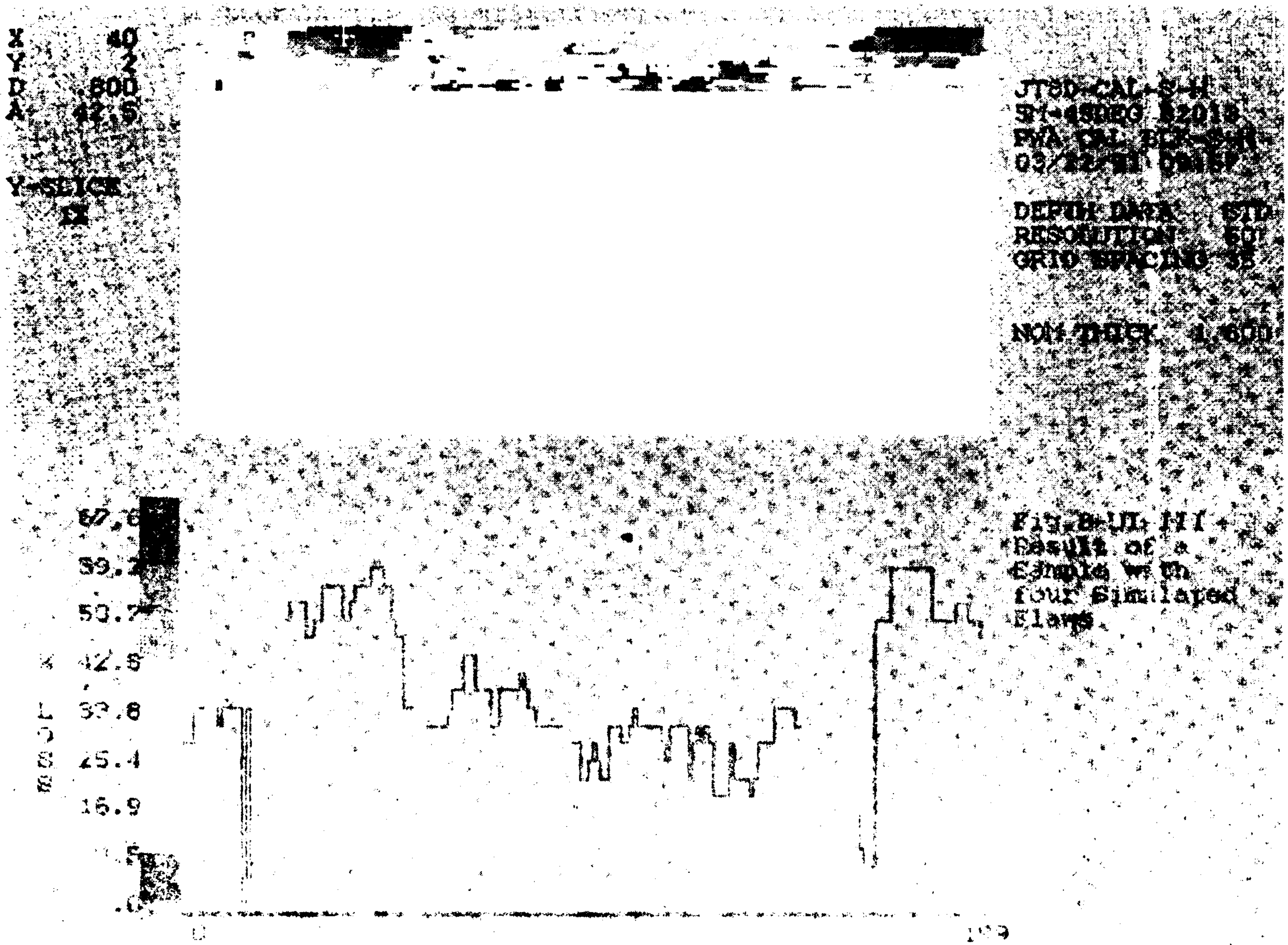


FIGURE 11. ULTRASONIC SCANNER RESULTS OF FOUR SIMULATED FLAWS IN A PWA DRAIN BOSS SAMPLE

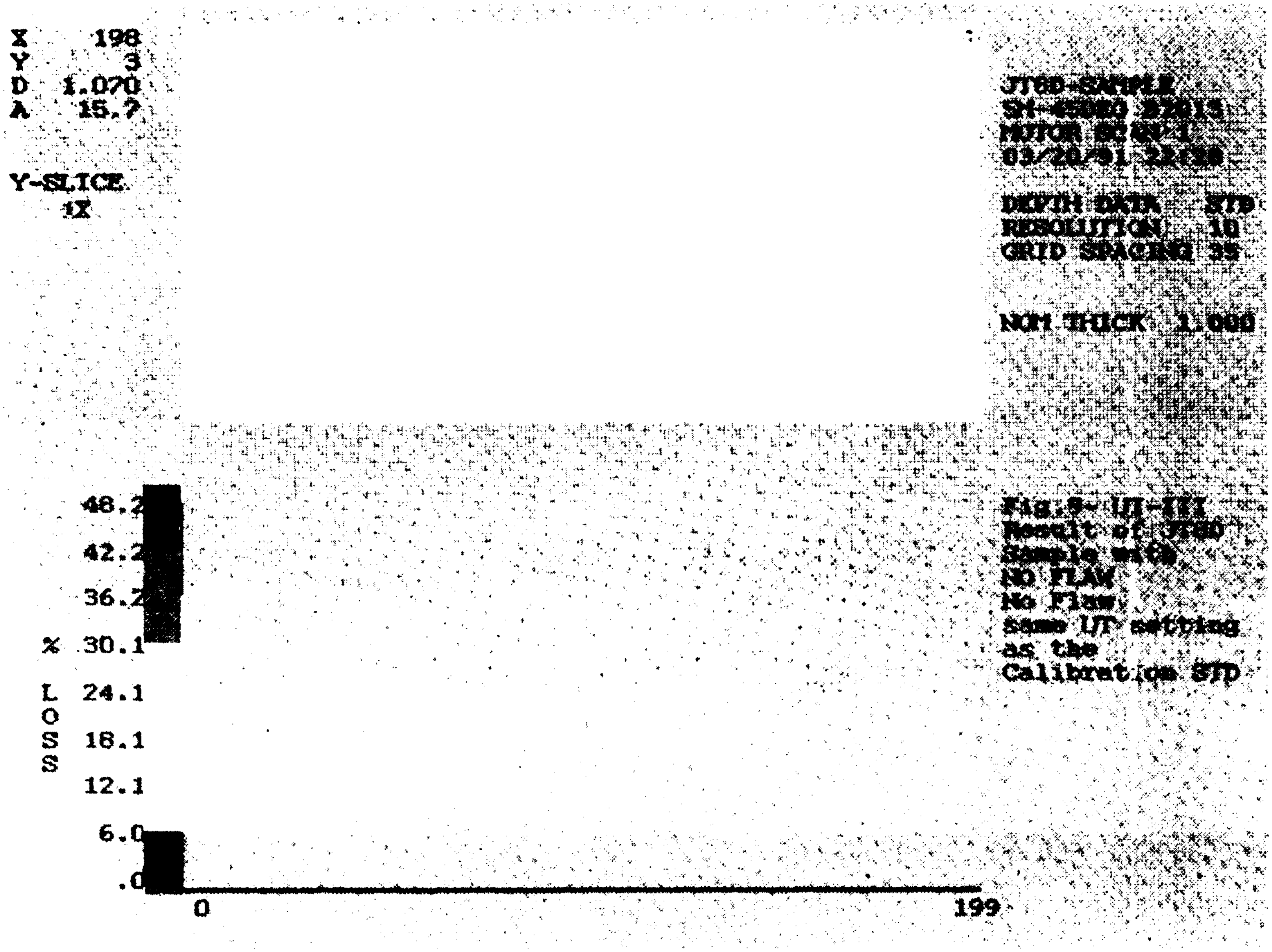


FIGURE 12 - ULTRASONIC SCANNER RESULTS ON A PWA DRAIN BOSS WITH NO FLAWS

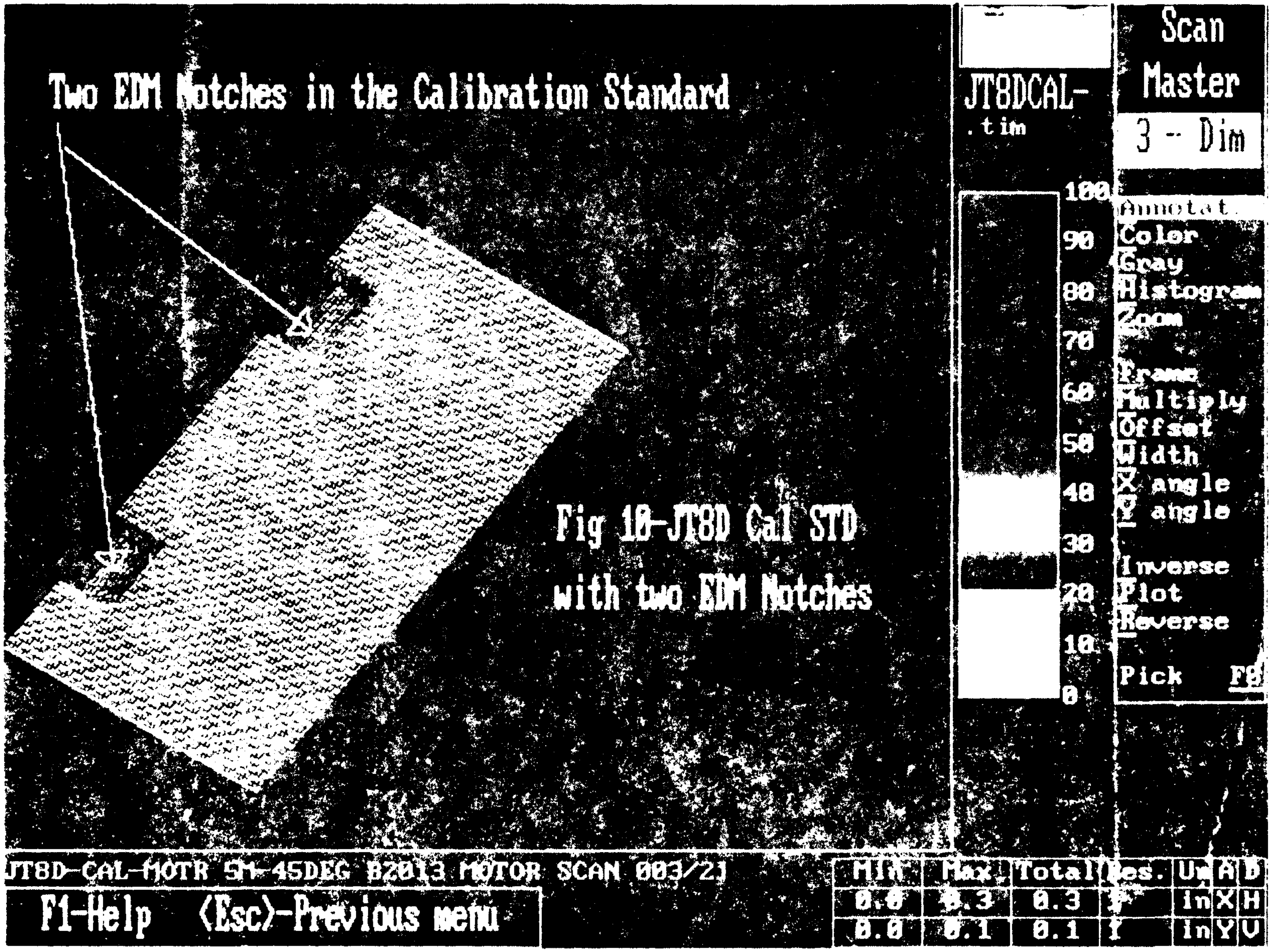


FIGURE 13 - CALIBRATION TEST STANDARD USING NEW SOFTWARE

CONCLUSIONS

The approach to determining JT8D engine component reliability problems by conducting an actuarial analysis of JT8D engine performance was successful. This analysis approach provided a comprehensive reliability overview of all JT8D engine operators, permitted identification of abnormal trends, and resulted in the isolation of specific JT8D engine components.

The Ultra Image III™ system provided an enhanced inspection procedure for JT8D engine outer combustor case boss welds. This inspection procedure provided a more comprehensive inspection and produced a permanent record of the weld condition. This enhanced capability would permit a damage tolerance assessment to be made of JT8D engine outer combustor case welds.

The following conclusions were developed from this study effort:

1. The FAA Air Carrier Aircraft Utilization & Propulsion Reliability Report contains comprehensive actuarial historical information on commercial aircraft engines.

2. Trending of FAA actuarial information regarding in-flight shutdowns and unscheduled engine removals can document specific aircraft engine reliability for an air carrier.

3. Review of component failures for a specific engine exhibiting a trend of excessive in-flight shutdowns and unscheduled engine removals can identify required modifications, non-destructive inspection procedure enhancements, and poor maintenance practices.

4. Enhanced ultrasonic inspection procedures can document cracking around the drain boss weld area of outer combustor cases on JT8D engines.

5. A successful ultrasonic inspection technique was developed and demonstrated for the JT8D engine outer combustor case drain boss area.

APPENDIX A

COMPONENT PERFORMANCE BY DISGUISED AIRLINE

Appendix A includes information gathered by FAA's Service Difficulty Reports (SDR) data base. It covers the timeframe of 1983 through April 1990 and specific information obtained included the following: operating condition that occurred, which engine incurred the damage, aircraft model and serial number, engine model and serial number, airline that experienced the incident, and date of the incident. A brief narrative was included in this information describing the incident and corrective action taken. The narrative documents if the take-off was aborted, if a flight turn-back occurred, or if the flight was diverted. This narrative also documents if an engine flameout occurred or if the engine was shut down by the flight crew. This information is useful in determining the safety-of-flight severity of each failure. Some minor failures might produce engine flameouts, but after a restart and normal operating parameters were established on the engine the flight would continue to its scheduled destination. Other failures produced severe vibration, massive oil pressure and quantity leaks, or resulted in the Exhaust Gas Temperature (EGT) exceeding the prescribed limits. These types of failures typically resulted in engine shutdown and flight turnback or diversion.

This information was used to trend JT8D performance by airline, aircraft model and year. The performance summary presented the following information:

- Incident occurrence, whether the component failure caused an aborted take-off, flight turn back, flight diversion, engine flameout / shutdown, or a combination thereof.

- Total number of incident occurrences per year.

- Identification of the component failure that caused the incident occurrence.

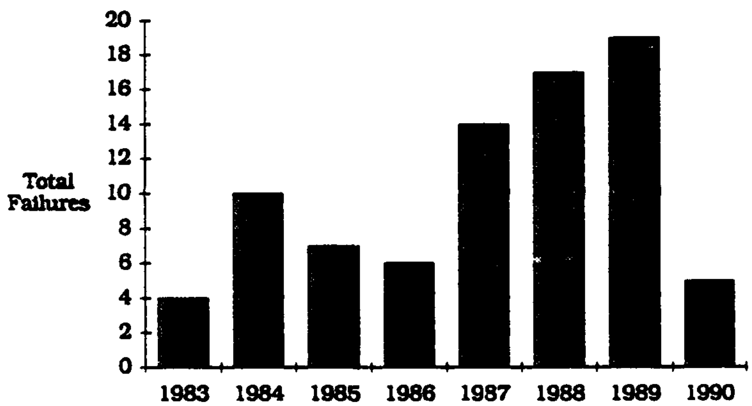
This in-depth component failure analysis was conducted on those masked airlines listed in table 13.

AIRLINE: BKB B-727 PERFORMANCE SUMMARY

INCIDENT OCCURRENCES

Take-Off Aborted, Flt Turn Back, Diverted	-	-	-	2	2	3	5	1
Engine Flameout/ Shutdown	4	6	3	2	1	6	3	3
Both Occurrences	-	4	3	3	9	8	11	1
Total Occurrences	4	10	6	7	12	17	19	5
CY	83	84	85	86	87	88	89	90

COMPONENT FAILURES

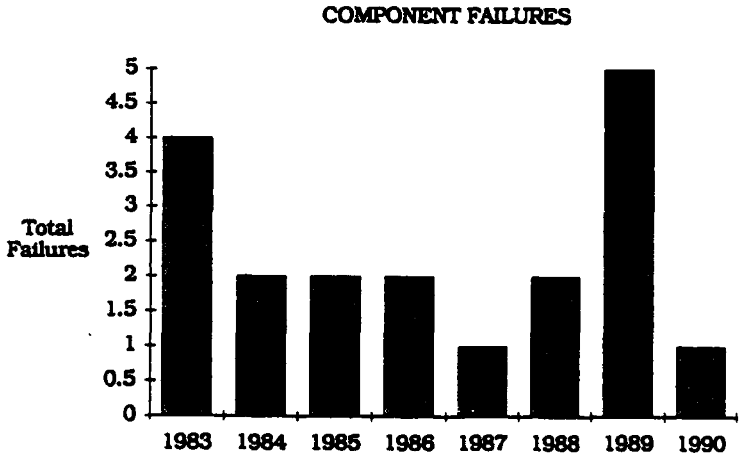


FAILURE ITEMS

									TTL
# 3 & #4 Bearings	-	-	-	-	-	4	1	-	5
# 6 Bearing Oil Tube	-	1	2	-	1	-	-	-	4
Other Oil Tube	-	-	-	-	1	1	2	3	7
Oil Sys Maint Errors	-	-	-	-	-	3	3	1	7
Fuel Control/Pump	-	1	-	-	-	-	2	-	3
Fan Blades	1	-	-	-	-	-	1	-	2
Compressor Blades	-	-	-	2	2	1	4	-	9
Turbine Blades	1	3	1	3	4	1	-	-	13
Fuel/Oil Heater Valve/Manifold	-	-	-	-	1	-	-	-	1
Other Failures	2	5	4	1	5	7	6	1	31
	4	10	7	6	14	17	19	5	82
CY	83	84	85	86	87	88	89	90	

INCIDENT OCCURRENCES

Take-Off Aborted, Flt Turn Back, Diverted	-	-	-	-	-	-	-	-
Engine Flameout/ Shutdown	4	-	1	2	-	1	2	-
Both Occurrences	-	1	1	-	1	1	2	1
Total Occurrences	4	1	2	2	1	2	4	1
CY	83	84	85	86	87	88	89	90



	1983	1984	1985	1986	1987	1988	1989	1990
COMPONENT FAILURES	4	2	2	2	1	2	5	1

FAILURE ITEMS

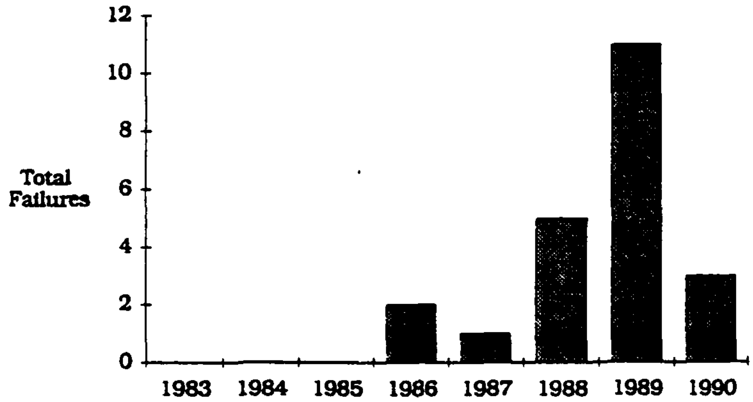
Bleed Air Duct/Valve	-	1	-	-	-	-	1	1	3
# 3 Bearing	2	-	-	-	-	-	-	-	2
Gearbox Bearings	1	-	-	1	-	-	-	-	2
Fuel Control/Pump	1	-	1	1	1	-	2	-	6
Turbine Blades	-	-	-	-	-	1	-	-	1
Seal Failures	-	-	-	-	-	1	-	-	1
Other Failures	-	1	1	-	-	-	2	-	4
	4	2	2	2	1	2	5	1	19
CY	83	84	85	86	87	88	89	90	

AIRLINE: CTA B-727 PERFORMANCE SUMMARY

INCIDENT OCCURRENCES

Take-Off Aborted, Flt Turn Back, Diverted	-	-	-	-	-	-	2	-
Engine Flameout/ Shutdown	-	-	-	1	-	2	2	1
Both Occurrences	-	-	-	1	1	2	3	2
Total Occurrences	0	0	0	2	1	4	7	3
CY	83	84	85	86	87	88	89	90

COMPONENT FAILURES



FAILURE ITEMS

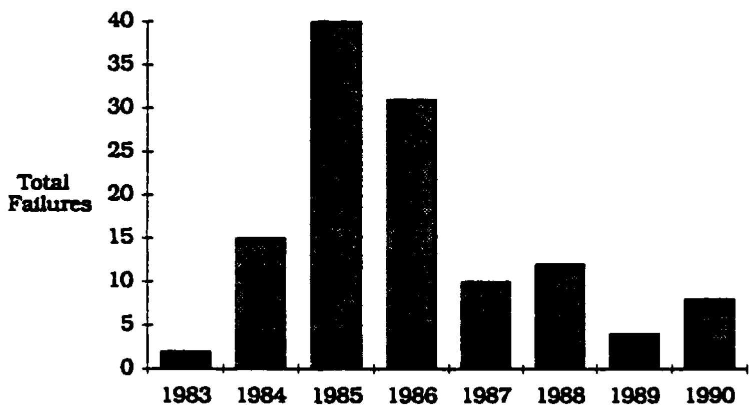
Bleed Air Manifold	-	-	-	-	1	-	4	-	5
# 6 Bearing Oil Tube	-	-	-	1	-	-	-	-	1
2nd Stg Turbine Disk	-	-	-	-	-	-	-	2	2
Fan Disk	-	-	-	1	-	-	-	-	1
Oil System Seals	-	-	-	-	-	1	1	-	2
Turbine Blades	-	-	-	-	-	1	1	-	2
Fuel System Items	-	-	-	-	-	-	2	-	2
Compressor Blades	-	-	-	-	-	-	1	-	1
FOD	-	-	-	-	-	2	-	-	2
Other	-	-	-	-	-	-	2	1	3
	0	0	0	2	1	4	11	3	21
CY	83	84	85	86	87	88	89	90	

AIRLINE: XYZ B-727 PERFORMANCE SUMMARY

INCIDENT OCCURRENCES

	CY 83	84	85	86	87	88	89	90
Take-Off Aborted, Flt Turn Back, Diverted	-	6	6	11	5	-	3	5
Engine Flameout/ Shutdown	1	2	13	8	-	2	2	2
Both Occurrences	1	4	13	11	3	5	2	1
Total Occurrences	2	12	32	30	8	7	7	8

COMPONENT FAILURES



FAILURE ITEMS

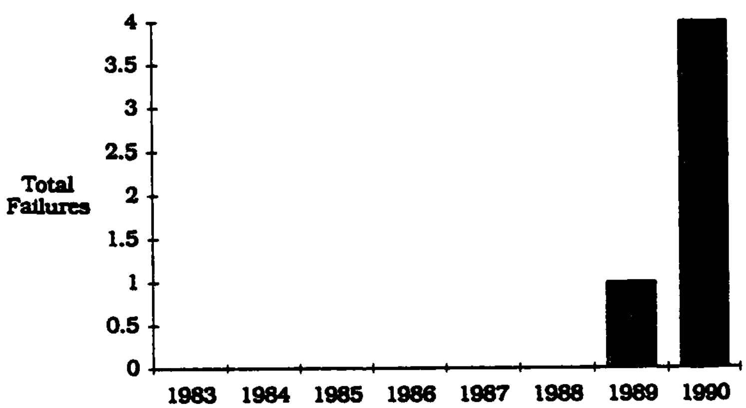
	CY 83	84	85	86	87	88	89	90	
Bleed Air Ducts/Valve	-	2	-	-	1	-	1	1	5
# 3 & #4 Bearings	-	3	3	3	-	-	-	-	9
# 6 Bearing Oil Tube	-	-	-	2	-	-	-	-	2
Oil Sys Maint Errors	-	-	2	-	-	-	-	-	2
Fuel Control/Pump	-	-	2	3	2	5	1	-	13
Fan Blades	1	-	-	1	-	-	-	-	2
Compressor Blades	-	2	1	2	-	-	-	-	5
Turbine Blades	-	2	4	2	-	-	-	-	8
Combustion Chamber	-	-	3	-	-	1	-	-	5
Tie Rod Bolt	-	-	2	-	1	-	-	-	2
Fuel/Oil Heater/ Valve Manifold	-	-	-	1	1	-	-	-	2
Other Failures	1	6	21	19	5	6	2	7	67
	2	15	40	31	10	12	4	8	122

AIRLINE: OPO B-727 PERFORMANCE SUMMARY

INCIDENT OCCURRENCES

Take-Off Aborted, Flt Turn Back, Diverted	NO DATA ON OPO UNTIL 1989.						-	2
Engine Flameout/ Shutdown							-	3
Both Occurrences							-	1
Total Occurrences	-	-	-	-	-	-	0	6
CY	83	84	85	86	87	88	89	90

(Note: No Data on OPO Until 1989)



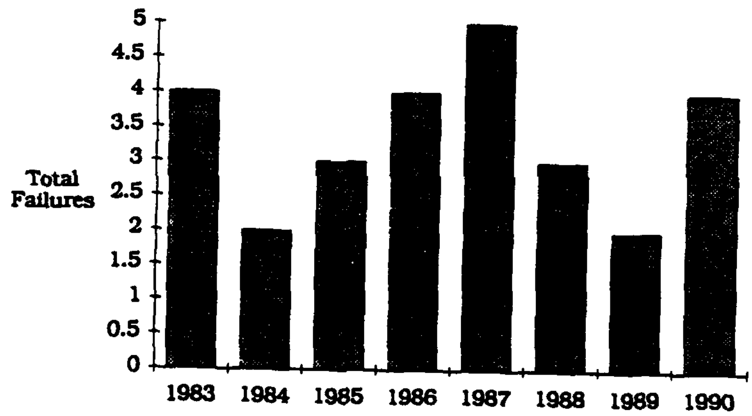
FAILURE ITEMS

									TTL
Bleed Air Duct/Valve	-	-	-	-	-	-	1	-	1
Fuel Pump	-	-	-	-	-	-	-	3	3
Other Failures	-	-	-	-	-	-	-	1	1
	-	-	-	-	-	-	1	4	5
CY	83	84	85	86	87	88	89	90	

INCIDENT OCCURRENCES

Take-Off Aborted, Flt Turn Back, Diverted	-	-	-	-	3	1	2	-
Engine Flameout/ Shutdown	3	2	2	2	-	1	-	1
Both Occurrences	1	-	-	-	2	1	-	3
Total Occurrences	4	2	2	2	5	3	2	4
CY	83	84	85	86	87	88	89	90

COMPONENT FAILURES



FAILURE ITEMS

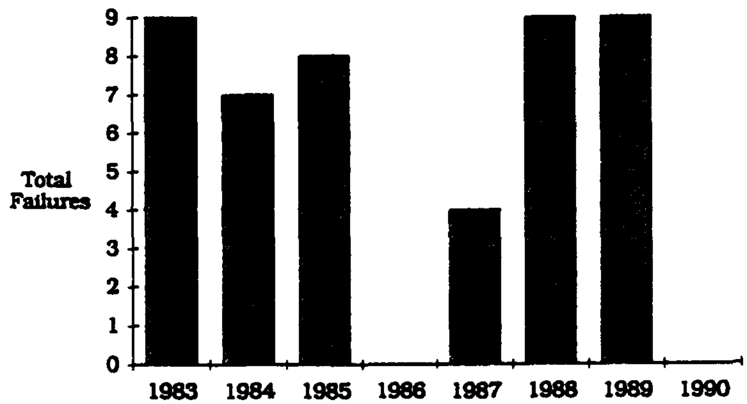
Bleed Air Duct/Valve	-	-	1	1	2	-	1	-	5
# 3/#4 Bearings	4	-	-	2	-	1	-	-	7
# 6 Bearing Oil Tube	-	-	1	-	-	1	-	-	2
Oil Sys Maint Errors	-	-	1	-	-	-	-	-	1
Compressor Blades	-	-	-	-	1	-	-	-	1
Turbine Blades	-	-	-	-	1	-	-	-	1
Fuel/Oil Heater Valve Manifold	-	-	-	-	-	1	1	-	1
Other Failures	-	2	-	1	1	-	-	4	9
	4	2	3	4	5	3	2	4	27
CY	83	84	85	86	87	88	89	90	

AIRLINE: ABC B-727 PERFORMANCE SUMMARY

INCIDENT OCCURRENCES

Take-Off Aborted, Flt Turn Back, Diverted	-	4	5	-	3	6	7	-
Engine Flameout/ Shutdown	6	7	7	-	3	8	7	-
Both Occurrences	-	4	5	-	3	5	5	-
Total Occurrences	6	15	17	0	9	19	19	0
CY	83	84	85	86	87	88	89	90

COMPONENT FAILURES



FAILURE ITEMS

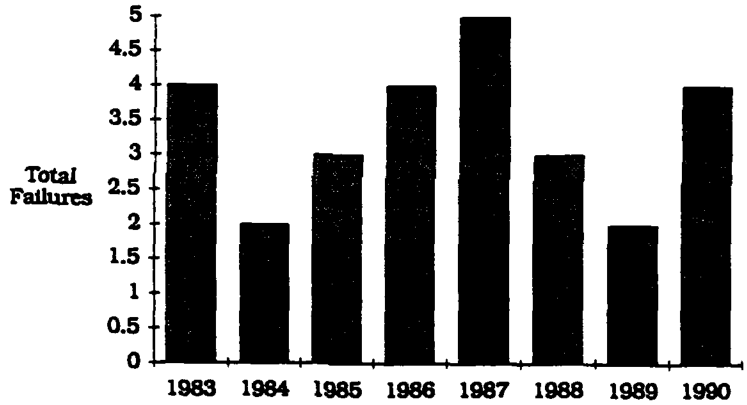
Bleed Air Duct/Valve	-	-	-	-	1	1	1	-	3
# 3/#4 Bearings	-	-	1	-	-	-	-	-	1
# 6 Bearing Oil Tube	3	-	-	-	-	-	-	-	3
Oil Sys Maint Errors	2	-	-	-	1	-	-	-	3
Fuel Control/ Pump	1	1	2	-	-	2	2	-	8
Compressor Blades	1	-	1	-	-	1	-	-	3
Turbine Blades	1	-	-	-	-	1	1	-	3
Fuel/Oil Heater Valve Manifold	-	1	-	-	1	1	-	-	3
Other Failures	1	5	4	-	1	3	5	-	19
	9	7	8	0	4	9	9	0	46
CY	83	84	85	86	87	88	89	90	

AIRLINE: RAB B-727 PERFORMANCE SUMMARY

INCIDENT OCCURRENCES

Take-Off Aborted, Flt Turn Back, Diverted	-	-	-	-	3	1	2	-
Engine Flameout/ Shutdown	3	2	2	2	-	1	-	1
Both Occurrences	1	-	-	-	2	1	-	3
Total Occurrences	4	2	2	2	5	3	2	4
CY	83	84	85	86	87	88	89	90

COMPONENT FAILURES



FAILURE ITEMS

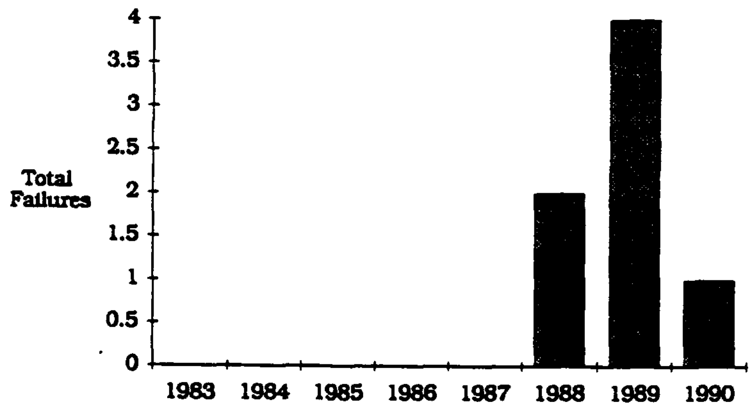
Bleed Air Duct/Valve	-	-	1	1	2	-	1	-	5
# 3 & #4 Bearings	4	-	-	2	-	1	-	-	7
# 6 Bearing Oil Tube	-	-	1	-	-	1	-	-	2
Oil Sys Maint Errors	-	-	1	-	-	-	-	-	1
Compressor Blades	-	-	-	-	1	-		-	1
Turbine Blades	-	-	-	-	1	-	-	-	1
Fuel/Oil Heater Valve/Manifold	-	-	-	-	-	-	1	-	1
Other Failures	-	2	-	1	1	1	-	4	9
	4	2	3	4	5	3	2	4	27
CY	83	84	85	86	87	88	89	90	

AIRLINE: CTA B-737 PERFORMANCE SUMMARY

INCIDENT OCCURRENCES

Take-Off Aborted, Flt Turn Back, Diverted	-	-	-	-	-	1	1	-
Engine Flameout/ Shutdown	-	-	-	-	-	-	-	-
Both Occurrences	-	-	-	-	-	-	3	1
Total Occurrences	0	0	0	0	0	1	4	1
CY	83	84	85	86	87	88	89	90

COMPONENT FAILURES



FAILURE ITEMS

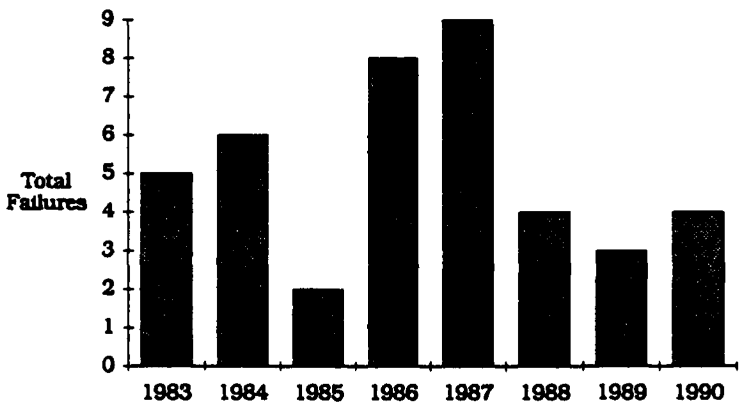
									TTL
13th Stage Manifold	-	-	-	-	-	1	-	-	1
Turbine Blades	-	-	-	-	-	-	2	-	2
Diffuser Case	-	-	-	-	-	-	1	-	1
Control Cable	-	-	-	-	-	-	1	-	1
FOD	-	-	-	-	-	-	-	1	1
Other Failures	-	-	-	-	-	1	-	-	1
	-	-	-	-	-	2	4	1	7
CY	83	84	85	86	87	88	89	90	

AIRLINE: MNO B-737 PERFORMANCE SUMMARY

INCIDENT OCCURRENCES

	CY 83	84	85	86	87	88	89	90
Take-Off Aborted, Flt Turn Back, Diverted	-	-	-	1	-	-	-	-
Engine Flameout/ Shutdown	-	1	-	1	2	1	-	-
Both Occurrences	-	-	-	1	-	-	-	-
Total Occurrences	0	1	0	3	2	1	0	0

COMPONENT FAILURES



FAILURE ITEMS

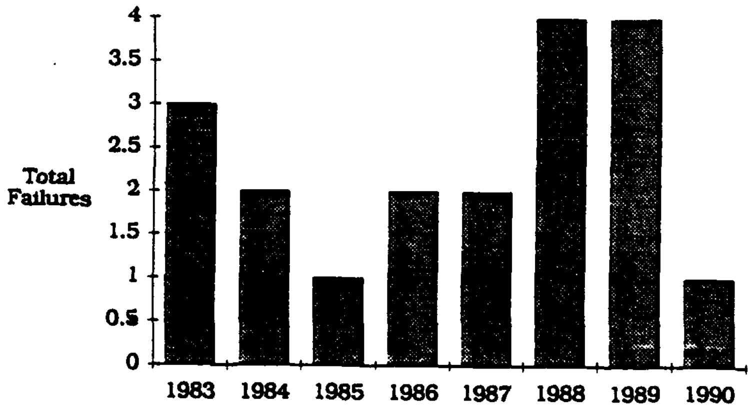
	CY 83	84	85	86	87	88	89	90	
# 3 Bearings	-	-	-	3	2	1	-	-	6
Other Bearings	-	-	-	-	3	-	-	-	3
Oil Sys Components	-	-	-	-	1	1	-	-	2
Gearbox	-	-	1	-	1	-	-	-	2
Case Failure	-	1	-	-	-	-	1	1	3
Fan Blades	1	-	-	-	-	-	-	-	1
Turbine Blades	-	1	-	-	-	-	1	2	4
Compressor Blades	1	-	-	-	-	-	-	1	2
Compressor Spacer	-	-	-	3	-	-	1	-	4
Air Seal	-	-	-	1	1	-	-	-	2
Turbine Disk	-	-	1	-	-	-	-	-	1
Fan/Comp/Turbine	2	1	-	-	-	-	-	-	3
Fuel Control/Pump	-	1	-	1	1	-	-	-	3
Fuel Manifold	-	1	-	-	-	-	-	-	1
FOD	1	-	-	-	-	2	-	-	3
	5	6	2	8	9	4	3	4	41

AIRLINE: RAB B-737 PERFORMANCE SUMMARY

INCIDENT OCCURRENCES

Take-Off Aborted, Flt Turn Back, Diverted	-	-	-	1	1	2	-	-
Engine Flameout/ Shutdown	-	-	1	-	1	1	2	1
Both Occurrences	-	-	-	-	-	-	-	-
Total Occurrences	0	0	1	1	2	3	2	1
CY	83	84	85	86	87	88	89	90

COMPONENT FAILURES



FAILURE ITEMS

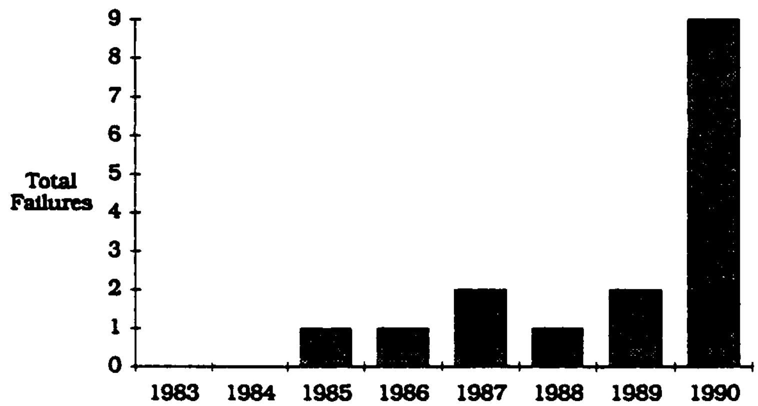
									TTL
Bearings	1	-	-	-	-	1	-	-	2
Oil Sys Components	-	-	-	-	-	-	1	-	1
Main Oil Screen	-	-	-	-	-	-	1	-	1
Turbine Blades	1	-	-	-	-	2	-	-	3
Compressor	-	-	-	-	-	-	-	1	1
Intermediate Case	1	-	-	-	-	-	-	-	1
Fuel Systems	-	-	1	-	1	-	-	-	2
FOD	-	1	-	-	1	-	-	-	2
Other Failures	-	1	-	2	-	1	2	-	6
	3	2	1	2	2	4	4	1	19
CY	83	84	85	86	87	88	89	90	

AIRLINE: GGA B-737 PERFORMANCE SUMMARY

INCIDENT OCCURRENCES

Take-Off Aborted, Flt Turn Back, Diverted	-	-	-	1	1	1	-	1
Engine Flameout/ Shutdown	-	-	-	-	-	-	-	-
Both Occurrences	-	-	1	-	1	1	1	1
Total Occurrences	0	0	1	1	2	2	1	2
CY	83	84	85	86	87	88	89	90

COMPONENT FAILURES

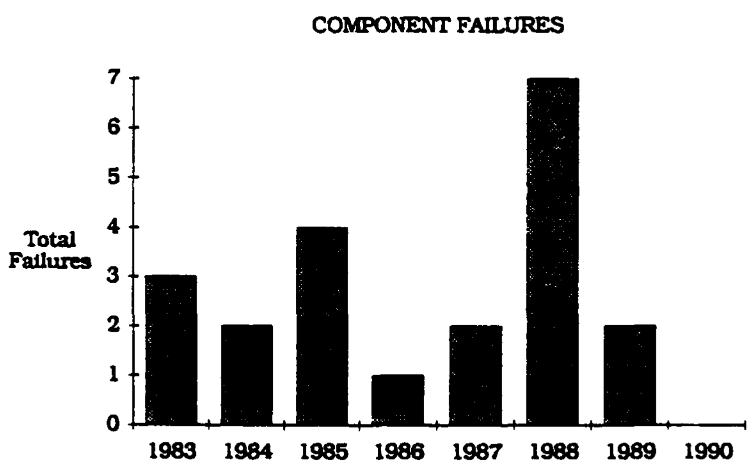


FAILURE ITEMS

									TTL
Bleed Air Ducts/Valve	-	-	-	1	-	-	-	2	8
# 6 Bearing Oil Tube	-	-	1	-	-	-	-	1	3
Compressor Blades	-	-	-	-	-	1	-	1	4
Other Failures	-	-	-	-	2	-	2	5	2
	-	-	1	1	2	1	2	9	43
CY	83	84	85	86	87	88	89	90	

INCIDENT OCCURRENCES

Take-Off Aborted, Flt Turn Back, Diverted	-	-	-	-	1	1	1	1
Engine Flameout/ Shutdown	3	1	1	-	1	-	1	-
Both Occurrences	-	1	2	1	-	3	-	-
Total Occurrences	3	2	3	1	2	4	2	0
CY	83	84	85	86	87	88	89	90



FAILURE ITEMS

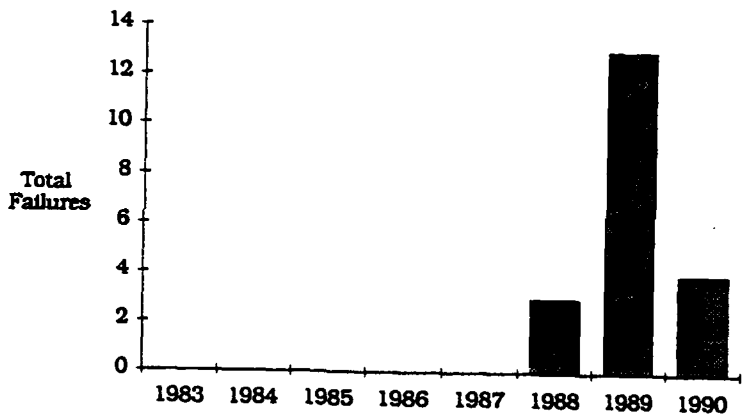
									TTL
# 3 & #4 Bearings	-	-	1	1	-	-	-	-	2
Oil Sys Maint Errors	-	1	-	-	-	-	-	-	1
Fuel Control/Pump	-	-	-	-	-	1	-	-	1
Turbine Blades	-	-	2	-	-	2	-	-	4
FOD Damage to Eng	2	-	-	-	1	3	1	-	7
Other Failures	1	1	1	-	1	1	1	-	6
	3	2	4	1	2	7	2	-	21
CY	83	84	85	86	87	88	89	90	

AIRLINE: CTA DC-9 PERFORMANCE SUMMARY

INCIDENT OCCURRENCES

Take-Off Aborted, Flt Turn Back, Diverted	-	-	-	-	-	1	6	4
Engine Flameout/ Shutdown	-	-	-	-	-	-	2	-
Both Occurrences	-	-	-	-	-	-	2	-
Total Occurrences	-	-	-	-	-	1	10	4
CY	83	84	85	86	87	88	89	90

COMPONENT FAILURES



FAILURE ITEMS

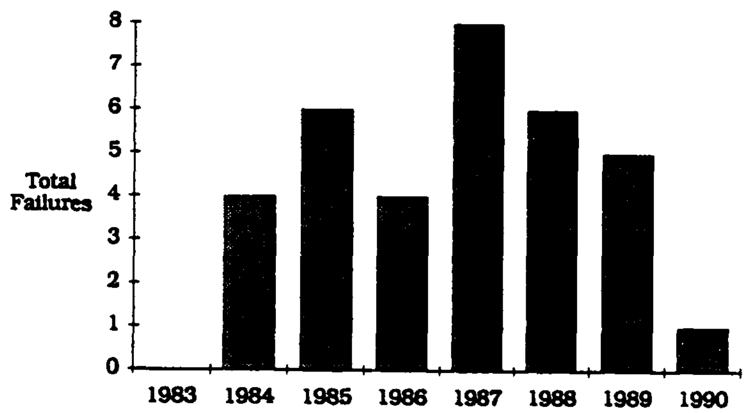
									TTL
Bleed Air Duct/Valve	-	-	-	-	-	-	4	1	5
# 3 Bearing	-	-	-	-	-	-	3	-	3
Other Bearings	-	-	-	-	-	-	1	-	1
Fuel Oil Cooler	-	-	-	-	-	1	-	-	1
Oil System	-	-	-	-	-	-	2	-	2
Fire Warning System	-	-	-	-	-	-	1	-	1
Turbine Blades	-	-	-	-	-	-	2	2	4
Other	-	-	-	-	-	2	-	1	3
						3	13	4	20
CY	83	84	85	86	87	88	89	90	

AIRLINE: DDD DC-9 PERFORMANCE SUMMARY

INCIDENT OCCURRENCES

Take-Off Aborted, Flt Turn Back, Diverted	-	1	-	6	2	1	2	-
Engine Flameout/ Shutdown	-	1	-	-	2	1	2	-
Both Occurrences	-	-	2	1	2	1	-	1
Total Occurrences	0	2	2	7	6	3	4	1
CY	83	84	85	86	87	88	89	90

COMPONENT FAILURES



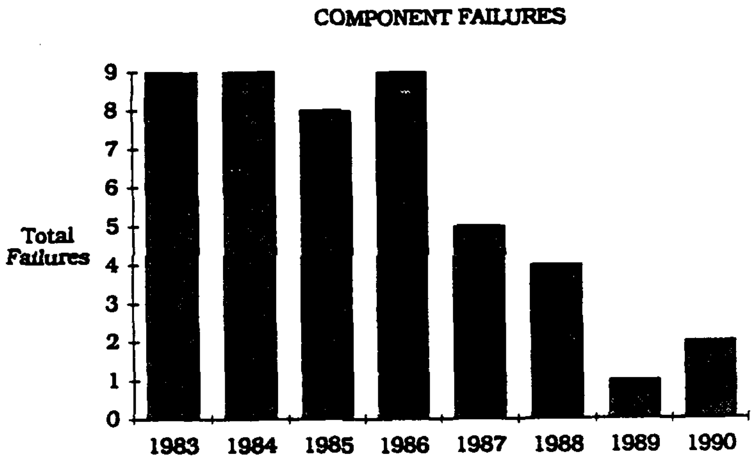
FAILURE ITEMS

									TTL
Oil Sys Maint Errors	-	-	-	-	-	-	1	-	1
Fuel Control/Pump	-	-	1	-	1	1	-	-	3
Turbine Blades	-	2	3	1	2	-	-	-	8
Other Failures	-	2	2	3	5	5	4	1	22
	-	4	6	4	8	6	5	1	34
CY	83	84	85	86	87	88	89	90	

AIRLINE: GGA DC-9 PERFORMANCE SUMMARY

INCIDENT OCCURRENCES

Take-Off Aborted, Flt Turn Back, Diverted	1	2	-	5	3	2	2	2
Engine Flameout/ Shutdown	1	1	2	1	-	-	-	-
Both Occurrences	-	-	3	3	2	-	-	-
Total Occurrences	2	3	5	9	5	2	2	2
CY	83	84	85	86	87	88	89	90



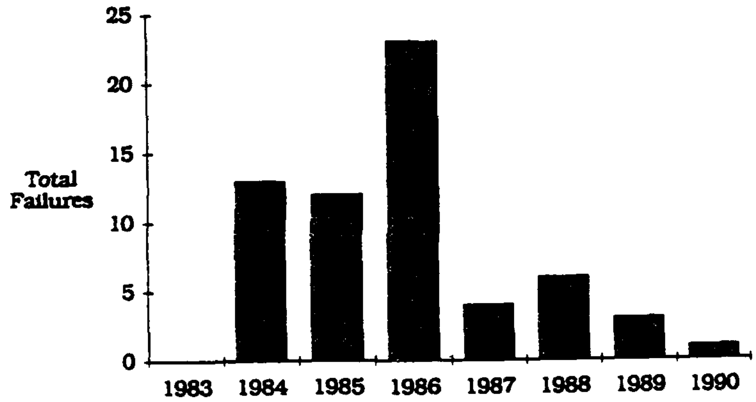
FAILURE ITEMS

									TTL
Bleed Air Ducts/Valve	-	-	-	1	1	1	-	-	3
# 3 & #4 Bearings	-	-	1	-	-	-	-	-	1
# 6 Bearing Oil Tube	-	1	-	1	-	-	-	-	2
Oil Sys Maint Errors	-	-	-	1	-	1	-	-	2
Fan Blades	-	-	-	1	-	-	-	-	1
Compressor Blades	-	-	1	-	-	-	-	-	1
Turbine Blades	5	2	2	2	1	1	-	-	13
Combustion Chamber	-	-	1	-	-	-	-	-	1
Cases	1	1	-	-	-	-	-	-	2
Other Failures	3	5	3	3	3	1	1	2	21
	9	9	8	9	5	4	1	2	47
CY	83	84	85	86	87	88	89	90	

INCIDENT OCCURRENCES

Take-Off Aborted, Flt Turn Back, Diverted	-	2	4	13	-	2	2	-
Engine Flameout/ Shutdown	-	1	2	3	-	3	-	-
Both Occurrences	-	-	2	6	1	-	1	1
Total Occurrences	0	3	8	22	1	5	3	1
CY	83	84	85	86	87	88	89	90

COMPONENT FAILURES



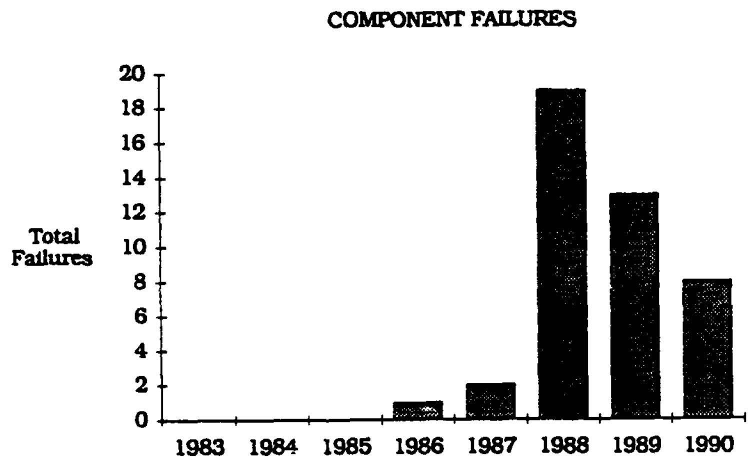
FAILURE ITEMS

Bleed Air Ducts/Valve	-	-	-	-	1	1	-	-	2
# 3 & #4 Bearings	-	-	1	-	-	-	-	-	1
Oil Sys Maint Errors	-	-	1	3	-	-	-	-	4
Fuel Control/Pump	-	1	-	-	-	2	-	-	3
Compressor Blades	-	-	1	-	-	-	-	-	1
Turbine Blades	-	1	1	3	1	-	-1	-	7
Combustion Chamber	-	1	-	1	-	-	-	-	2
Fuel/Oil Heater									-
Valve/Manifold	-	-	1	5	-	1	-	-	7
Fuel Nozzle Coking/ Heat Shield	-	-	-	-	1	2	-	-	3
Case Failures	-	1	1	2	-	-	-	-	4
Other Failures		9	6	9	1	-	2	1	28
	-	13	12	23	4	6	3	1	62
CY	83	84	85	86	87	88	89	90	

AIRLINE: BKB DC-9 PERFORMANCE SUMMARY

INCIDENT OCCURRENCES

	83	84	85	86	87	88	89	90
Take-Off Aborted, Flt Turn Back, Diverted	-	-	-	-	-	6	7	7
Engine Flameout/ Shutdown	-	-	-	-	-	3	2	1
Both Occurrences	-	-	-	1	2	9	3	-
Total Occurrences	0	0	0	1	2	18	12	8
CY	83	84	85	86	87	88	89	90



FAILURE ITEMS

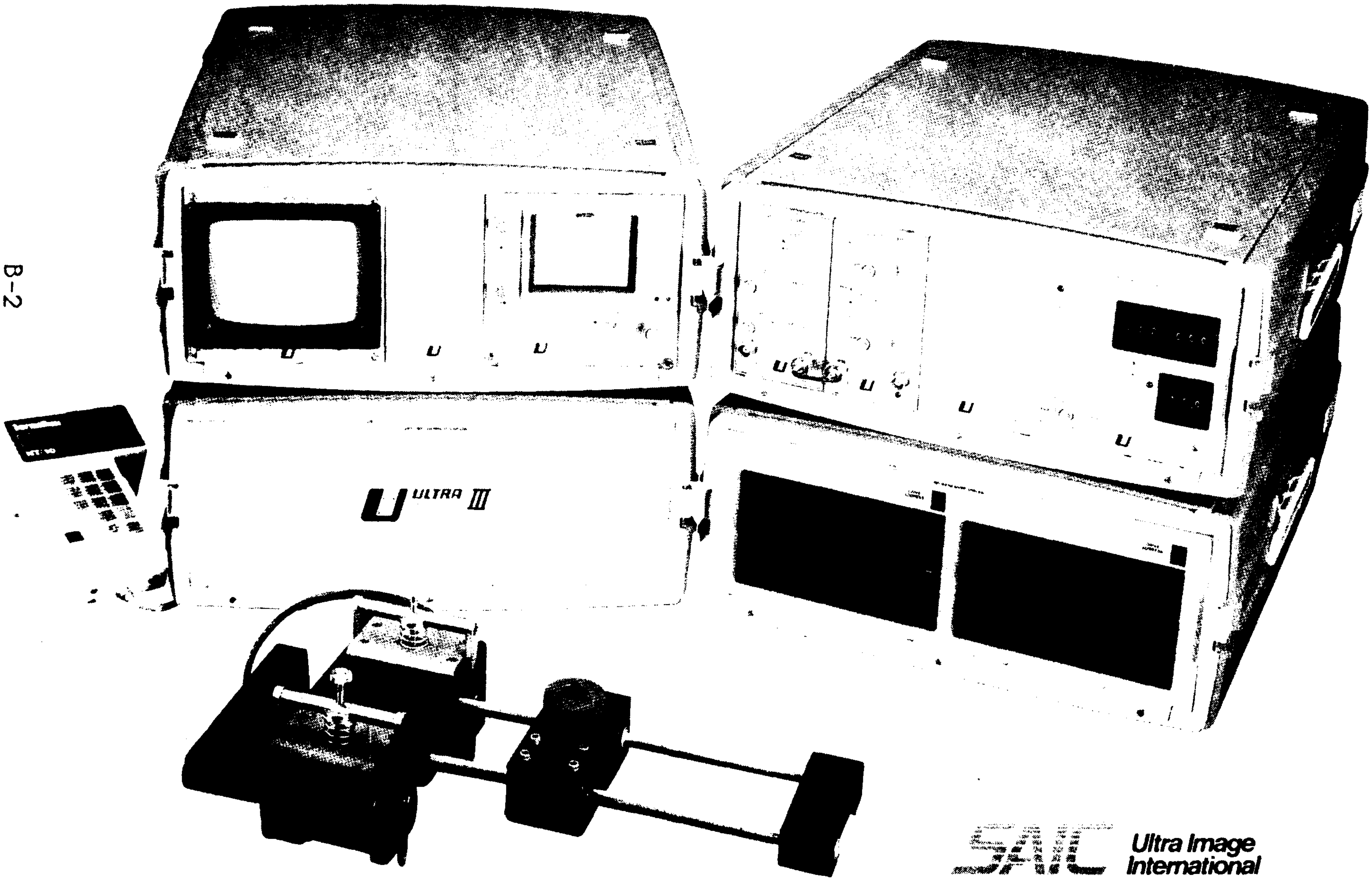
	83	84	85	86	87	88	89	90	TTL
Bleed Air Ducts/Valve	-	-	-	-	-	3	3	2	8
# 3 & #4 Bearings	-	-	-	-	-	1	2	-	3
Oil Sys Maint Errors	-	-	-	-	-	2	-	2	4
Fuel Control/Pump	-	-	-	-	-	2	-	-	2
Compressor Blades	-	-	-	1	-	-	1	-	2
Fan Blades	-	-	-	-	-	1	-	-	1
Turbine Blades	-	-	-	-	1	2	-	-	3
Fuel/Oil Heater Valve/Manifold	-	-	-	-	-	2	1	-	3
# 6 Oil Tube	-	-	-	-	-	-	-	1	1
Combustors	-	-	-	-	1	-	1	-	2
Other Failures	-	-	-	-	-	6	5	3	14
	0	0	0	1	2	19	13	8	43
CY	83	84	85	86	87	88	89	90	

APPENDIX B

ULTRA IMAGE III™ SPECIFICATIONS

ULTRA III

AN INTEGRITY ASSURANCE SYSTEM



SAIC Ultra Image International

A Division of Science Applications International Corporation

Two Shaw's Cove, New London, Ct 06320 203-442-0100

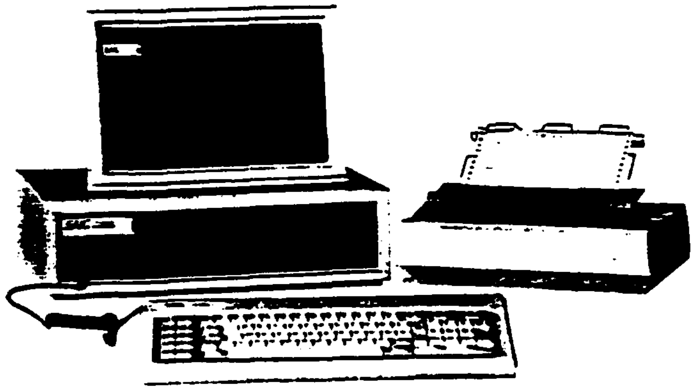
ULTRA™ IMAGE III
AN INTEGRITY ASSURANCE SYSTEM

SAIC Ultra Image International
A Division of Science Applications International Corporation

ULTRA IMAGE™ III SYSTEM SPECIFICATIONS

- Power Required: 90 to 250 VAC, 44 to 440 Hz, 2.5 amps except UI-3300 (110/220 VAC, 50-60 Hz, 0.5 amp). Total power draw is less than 300 volt-amps.
- Modes of Operation: straight beam or angle beam contact inspections.
- Scan Size: Variable from 2" × 4" to 20" × 40".
- Scan Resolution: Variable from .020" to .200" in 0.001" increments on a 100 point × 200 point grid.
- Scan Data Recorded — Header data and 20,000 points of depth and 20,000 amplitude.
- Maximum Scanning Speed — 150 scan points per second.
- Data Storage — 5¼ inch double sided, 96 tracks per inch, soft-sectored floppy disk.
- Documentation — Header data consisting of administrative, scan setup, calibration and instrument parameters.
- Scan Capabilities — Real time display with continuous monitoring of all instrument parameters.
- Analysis and Display Capabilities
  - Topographical plan view
    - 4 or 8 level gray
    - 4 or 8 level color
  - Selectable X and Y slices
  - Depth and amplitude readout for each scan point
  - Zoom window — 2X, 4X and 8X
- Size — 4 cases set up in less than 5 cubic ft. plus scanner.
- Weight — No case over 30 lbs., total weight less than 120 lbs.
- Set Up Time — 15 minutes.

UltraTEC™



*UltraTEC™ Technical Evaluation Center — an office-based workstation for advanced analysis capabilities

A STATE-OF-THE-ART NDT SYSTEM ... DESIGNED TO ACCOMMODATE NEW DEVELOPMENTS

The portable Ultra Image III on-line ultrasonic inspection system gives you a high-resolution detailed C-scan and B-scan image which is repeatable from test to test. A color display gives you the third dimension — for depth and/or amplitude determination and clarity of interpretation. The built-in software allows you to analyze all the available information under precise control and enables simulation of a top view regardless of transducer angle. The result is a substantial improvement in accuracy over hand-held ultrasonic inspection units. A permanent record lets you repeat any previous test under identical conditions and recall an image at any time for comparative analysis in both depth and amplitude. The ability to back integrate and communicate with peripheral devices not only brings ultimate confidence and reliability to today's nondestructive inspection needs with state-of-the-art technology, but allows you to take advantage of future developments.

Over the last several years, the Ultra Image III has been field-proven in a variety of remote and hostile environments around the world. First developed to make critical measurements on nuclear submarines, it has since been used from Alaska to the Arabian desert in oil and gas applications, to aircraft flight lines in Australia. It has proven highly effective in the nondestructive detection of corrosion, cracks, hydrogen blisters, composite delamination, and debonding in metal-to-metal and metal-to-nonmetal interfaces, including face sheet-to-honeycomb bonds.

*The Ultra Image III field team can now receive additional support via the new UltraTEC™ Technical Evaluation Center — an office-based workstation that communicates with the Ultra Image III on location via ordinary telephone lines or via data disk. Engineers in the office or laboratory can then display and analyze scan information, modify headers, and copy data as with the Ultra Image III. Or they can provide expert interpretation of data quickly to the field team, or provide them with such information as newly created headers or previously taken scan data. Anyone trained on the Ultra Image III system will also be able to operate the UltraTEC.

ULTRA IMAGE™ III EQUIPMENT SPECIFICATIONS

Module 3100 DISPLAY
- 5" Black & White Monitor (Color output available)
- 3½" A-Scan CRT

Module 3200 ULTRASONIC

Model 3201
- Pulser — maximum output 400 volts
- Damping — 10, 25,50,100 150 ohms
- Pulse Amplitude — 20, 40, 60, 80, 100 percent
- Pulse Width — LOW, HIGH

Model 3202
- Receiver
- Attenuation — 0-62 dB in 1 dB steps
- Filter — Broad Band, 1-6 MHz, 2-8 MHz, 4-8 MHz
- Function — Pitch-Catch, Pulse-Echo
- Detector — RF, Video

Model 3203
- Digital Thickness Gate
- Gate Delay — 0-99.9µ sec by 0.1µ sec, 0-999µ sec by 1µ sec
- Gate Width — 0-99µ sec by 0.1µ sec, 0-999µ sec by 1µ sec
- Scope Trigger Delay — 0-99.9µ sec by 0.1µ sec, 0-999µ sec by 1µ sec
- Range — 0.5, 1.0, 2.5, 12.5, 25.0, 50 inches
- Depth Resolution — 0.002, 0.004, 0.010, 0.050, 0.100, 0.200 inches
- Threshold, set through microprocessor — 1-100% in 1% steps
- Threshold Exceeded Indicator

Module 3300 FLOPPY DISK
- 2 5¼" Floppy Disk Drives — Formatted capacity 628K Bytes each

Module 3400 MICROPROCESSOR
- Z80A*-CPU (8 bit microprocessor)
- Operates at 4 MHz
- Memory 576K bytes expandable to 1M bytes
- 7-Slot Chassis
- Memory Management
- Floppy Disk Controller
- 640 × 480, 16 level graphics controller
- Calendar/clock

(All specifications subject to change without notice)

Contact Ultra Image International
Division of SAIC for
consultation on your testing problem.

*Trademark Zilog

APPENDIX C

NDI PROCEDURE DESCRIPTION

Ultrasonic Imaging On-Wing Inspection of JT8D Engine Case Boss Weld by Motorized Scanner.

1. Objective:
   Use of ultrasonic imaging method to inspect JT8D engine case boss weld

2. Reference:
   (a) PWA Ultrasonic Inspection of JT8D Combustion Chamber Outer Case, Video Tape, Part No. 804137, 10/30/86.

3. Equipment and Materials

   3.1 UI-III™ -- ultrasonic imaging system

   3.2 Transducer -- 5MHz, angle beam, 45 degrees, 3/8"

   3.3 Transducer Cable -- 25 feet

   3.4 PWA calibration block with EDM notches

   3.5 Power Cable -- 25 feet

   3.6 Couplant -- soap water

   3.7 Scanner -- UII/SAIC JT8D motorized scanner

   3.8 Disketter -- 5 1/4" double density, soft sector, 96 TPI

   3.9 Light, Mirror, Coveralls (clothing), Rags

   3.10 Notebook

4. Safety Precaution
   The engine must be in the POWER OFF position and in LOCK POSITION.
   All personnel performing the inspection shall wear safety goggles.

5. Calibration

   5.1 Preparation
   (a) Set up UI III™ system according to the Operations Manual
   (b) Load Program Disk -- Input Date and Time
   (c) Load Data Disk - (Preprogrammed Header Information as follows:)

GROUP A -		ADMINISTRATIVE DATA
1 PROJECT	=	JT8D-CAL-MOTOR
2 TASK	=	5M-45DEG B2013
3 SCAN	=	MOTOR SCAN 1
4 INSPECTOR	=	MCT/BED
5 PREV. SCAN REF	=	1
6 TRANSDUCER	=	5M B2013
7 CAL. BLOCK	=	2-HOLE
8 CREATED TIME	=	03/20/91 20:35
9 ACCESSED TIME	=	03/20/91 20.20

(c) Press the X button in clockwise direction. The transducer will activate scanning (clockwise) in a circumferential direction, stopping at the end of the track (Note 1). One line of information is obtained. Reverse the switch to counterclockwise direction. Press the X button to return the transducer to the starting point.

(d) Jog the Y Button to advance the transducer in increments of one grid.

(e) Repeat process 5.2 (c) above for 10 lines of information.

(f) Save the data on diskette.

(g) perform preliminary analysis on these data. Compare data with previous data. Calibration data must be repeatable before the on-wing test can begin.

6. Inspection

CAUTION! SAFETY RULES MUST BE FOLLOWED THROUGHOUT INSPECTION (See Section 4).

(a) Install and fasten JT8D motorized scanner on boss weld to be tested. Use mirror and light to assist in positioning scanner.

(b) Use sequence scan to modify header information of boss weld to be inspected.

(c) Perform the scan, as stated in Sections 5.2 (b) - 5.2 (g).

(d) For additional boss weld inspections, proceed as stated in 6 (b) - 6 (c).

7. Take notes on the test as applicable. At this point, the inspection is complete.

Note: 1: The END of the track for the AFT and PS4 drain boss welds is the end of the 240 degree range, i.e., from 0-240 degree. The END of the track for the FORWARD drain boss weld is performed in two separate parts to avoid interference from the slanted drain tubing nearby (0-110 degrees and 130-240 degrees range).

☆U.S. GOVERNMENT PRINTING OFFICE: 1992 - 604-061/60058